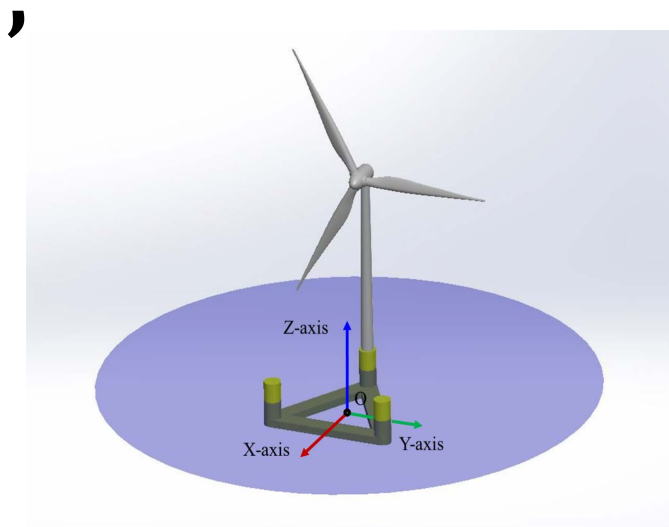
NTNU | 中国海洋大学 Ocean University of China | EERA DeepWind CONFERENCE 2025

# Load effect analysis of semi-submersible floating wind turbine tower, considering sum-frequency wave excitation


Haozhe Bai[1,2*], Shuaishuai Wang[2], Torgeir Moan[2], Kun Xu[1], Min Zhang[1] and Huajun Li[1]

[1] College of Engineering, Ocean University of China, Qingdao, China

[2] Department of Marine Technology, Norwegian University of Science and Technology, Trondheim, Norway

## Introduction

**Previous Experimental Results**

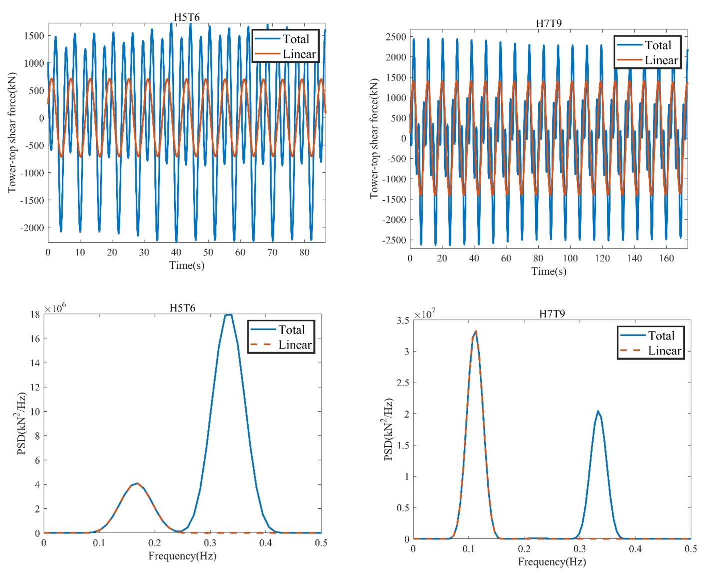


Fig 1. What are WIHF dynamic responses of semi-submersible FWT

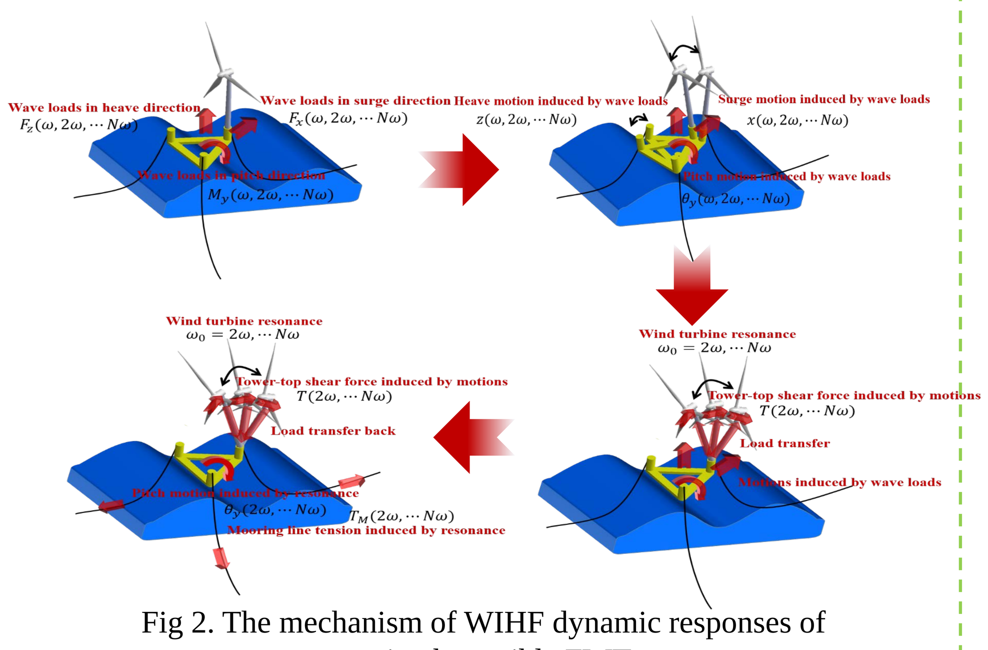
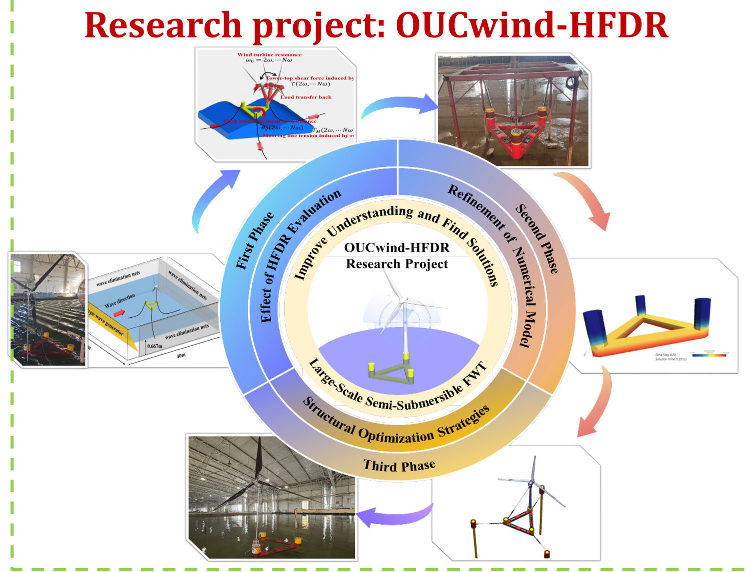


Fig 2. The mechanism of WIHF dynamic responses of semi-submersible FWT

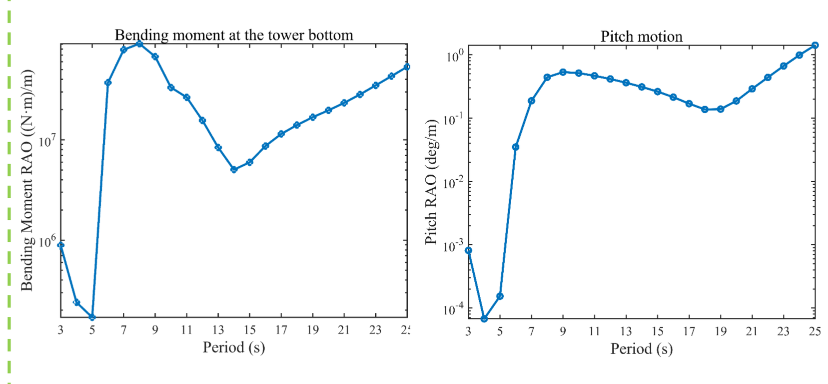
**Research project: OUCwind-HFDR**



- Most adopted type: **semi-submersible FWT**
- The **sum-frequency wave load effects on semi-submersible FWT** have attracted minimal focus
- A comprehensive and progressive research project "OUCwind-HFDR"
- **Investigates the WIHF structural responses of a semi-submersible FWT under various environmental conditions**

## Environmental Condition Design

➢ *RAO analysis*

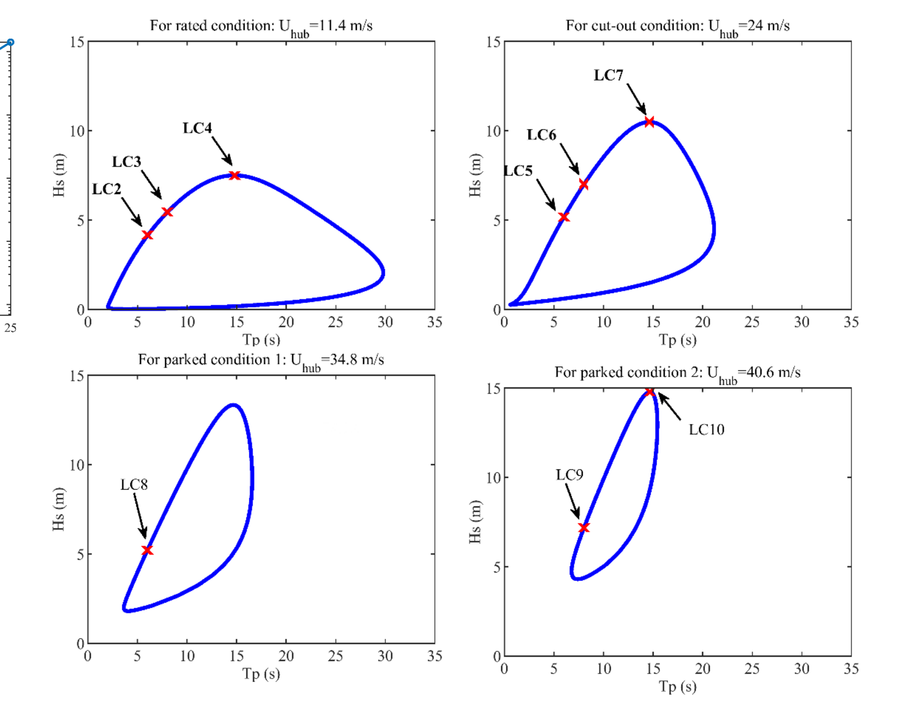


➢ *Wind conditions:* four typical conditions including cut-in, rated, cut-out, and parked conditions.

➢ *Wave conditions:*

- *Cut-in condition:* significant wave height of 3 m and a peak period of 6 s is selected
- *Rated, cut-out, and parked conditions:*
  1. special wave period of 6s
  2. select based on the RAO analysis
  3. largest significant wave height

➢ *Contour figures to determine wave conditions*

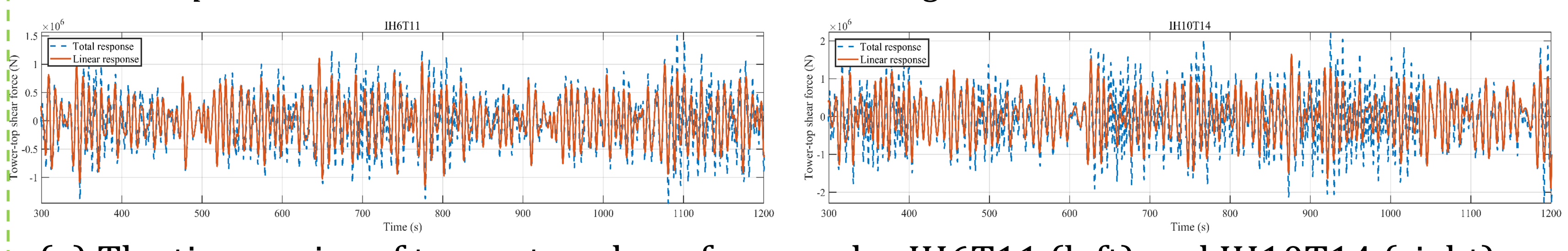


➢ *Ten typical wind and wave combined conditions*

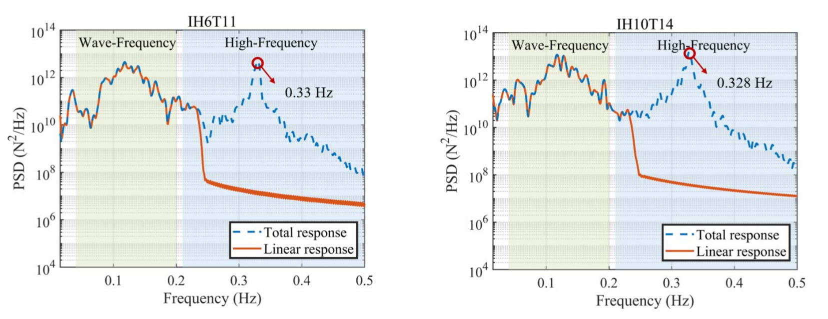
| Condition | Load cases | $U_{hub}$ (m/s) | TI | Hs (m) | Tp (s) |
|---|---|---|---|---|---|
| Cut-in condition | LC1 | 5 | 23.04% | 3.00 | 6.00 |
| Rated condition | LC2 | 11.4 | 13.41% | 4.15 | 6.00 |
| | LC3 | 11.4 | 13.41% | 5.44 | 8.00 |
| | LC4 | 11.4 | 13.41% | 7.50 | 14.78 |
| Cut-out condition | LC5 | 25 | 13.23% | 5.17 | 6.00 |
| | LC6 | 25 | 13.23% | 7.00 | 8.00 |
| | LC7 | 25 | 13.23% | 10.48 | 14.62 |
| Parked Condition | LC8 | 34.8 | 14.77% | 5.22 | 6.00 |
| | LC9 | 40.6 | 14.77% | 7.15 | 8.00 |
| | LC10 | 40.6 | 15.61% | 14.78 | 14.67 |

## Results and Discussion

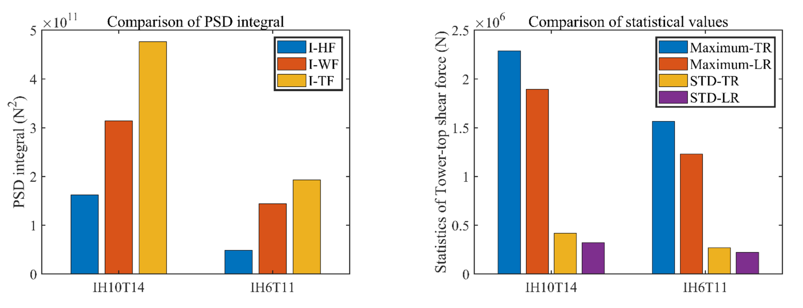
➢ *The experimental WIHF structural load under irregular wave condition*



(a) The time series of tower-top shear force under IH6T11 (left) and IH10T14 (right)



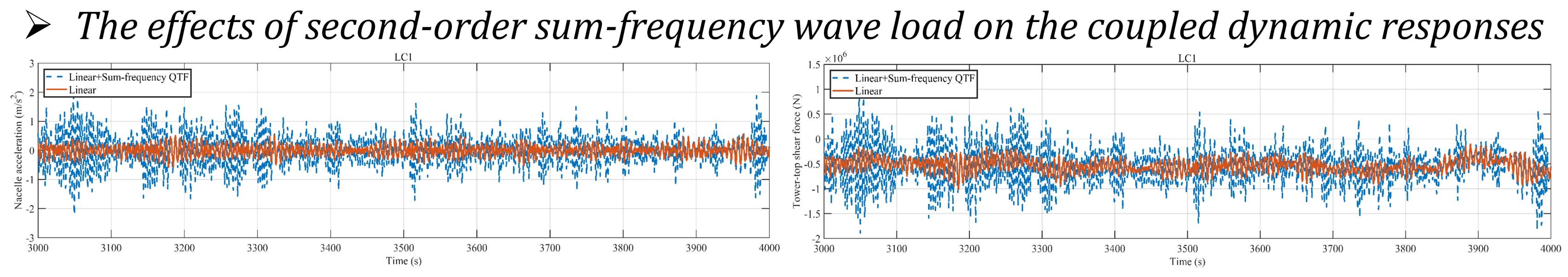
(b) The PSD of tower-top shear force under IH6T11 (left) and IH10T14 (right)



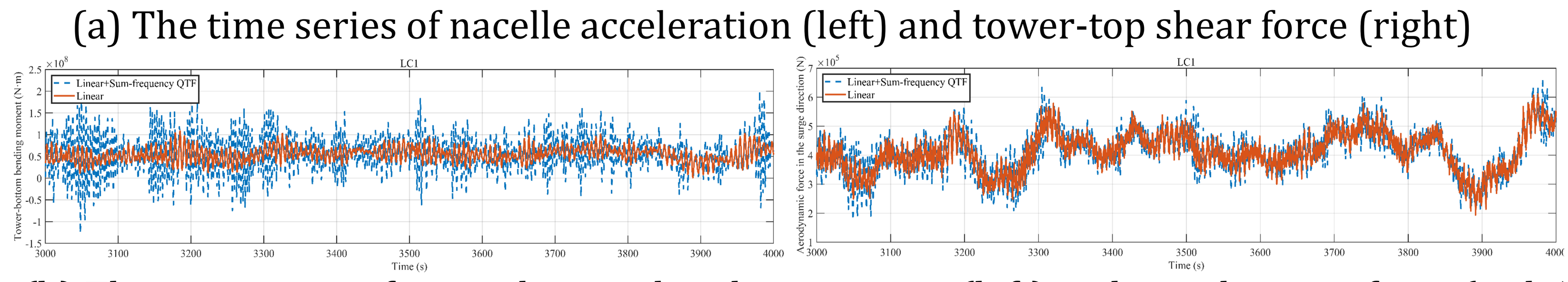
(c) The PSD integral (left) and statistics (right) of tower-top shear force

- The high-frequency peak frequencies are 0.33 Hz and 0.328 Hz, respectively, which are remarkably close to each other.
- A proportional coefficient α is defined by $I_{HF}/I_{TF}$. The αs under IH6T11 and IH10T14 reach to 0.25 and 0.34, respectively. Additionally, the maximum and STD of tower-top shear force are respectively underestimated by linear response by 21.57 % and 17.19 % under IH6T11, and 17.29 % and 23.39 % under IH10T14.

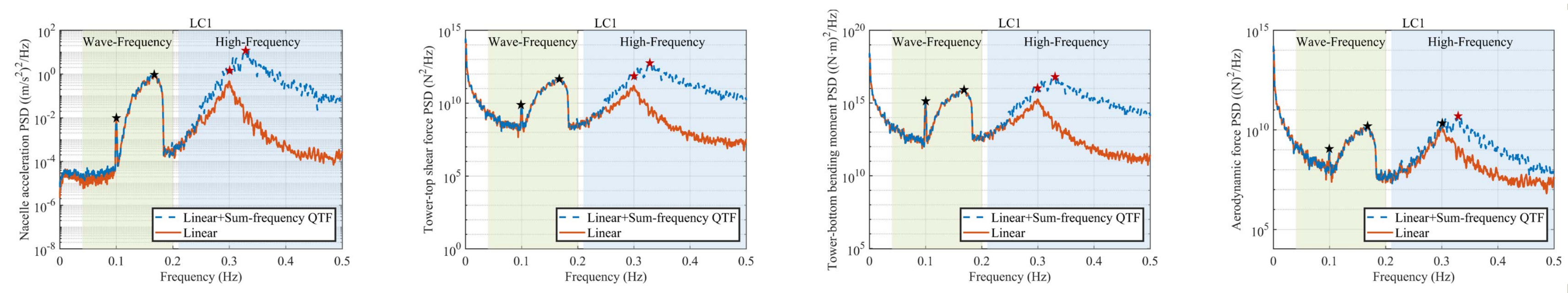
➢ *The effects of second-order sum-frequency wave load on the coupled dynamic responses*



(a) The time series of nacelle acceleration (left) and tower-top shear force (right)



(b) The time series of tower-bottom bending moment (left) and aerodynamic force (right)



(c) The PSDs of nacelle acceleration, tower-top shear force, tower-bottom bending moment, and aerodynamic force

- It could be observed that there are two peaks in the wave-frequency region. The left one equal to 0.1 Hz corresponds to the rotor rotational frequency (1P), and the right one corresponds to the wave peak period.
- Two peaks in the high-frequency region both have considerable disparities between NHM and LHM. Among these two peaks, the left one equal to 0.3 Hz is associated with the blade passing frequency (3P), and the right one close to 0.33 Hz is relevant with the natural frequency of the wind turbine with an elastic boundary.

## Conclusions

➢ *ULS check for DTU 10-MW reference wind turbine*

- Most checks of LHM pass except for the column buckling check under particularly severe conditions, and the rated condition is the most unfavourable condition.
- All checks of NHM fail to pass under rated, cut-out, and parked conditions. Moreover, as the wave conditions become more severe, the check coefficients of all checks are farther away from the safety criterion.

| Load condition | Hydrodynamic model | Yielding Check coefficient | Buckling check coefficient for shell | Buckling check coefficient for column |
|---|---|---|---|---|
| Cut-in LC1 | LHM | ***6.1784 (pass)*** | ***5.9084 (pass)*** | ***0.3782 (pass)*** |
| | NHM | ***2.2187 (pass)*** | ***1.5127 (pass)*** | ***0.8682 (pass)*** |
| Rated LC3 | LHM | ***1.8466 (pass)*** | ***1.7610 (pass)*** | ***0.8531 (pass)*** |
| | NHM | ***0.7285 (fail)*** | ***0.6023 (fail)*** | ***2.2439 (fail)*** |
| Cut-out LC6 | LHM | ***3.2189 (pass)*** | ***1.9339 (pass)*** | ***0.5558 (pass)*** |
| | NHM | ***0.4299 (fail)*** | ***0.2596 (fail)*** | ***3.6099 (fail)*** |
| Parked LC10 | LHM | ***2.0540 (pass)*** | ***1.9596 (pass)*** | ***1.2262 (fail)*** |
| | NHM | ***0.2820 (fail)*** | ***0.1882 (fail)*** | ***5.7328 (fail)*** |

➢ *Remarkable conclusions*

- **Experimental results show that WIHF structural loads are significant to the total structural loads under irregular wave conditions, and the extent of impact is positively correlated with the increase in the severity of sea conditions.**
- **The second-order high-frequency wave loads could amplify the high-frequency structural responses caused by the 3P and resonance effects.**
- **The second-order high-frequency wave loads could increase the aerodynamic force through increasing the components of the natural frequency of the wind turbine, but it has minor effects on the components of the rotational effects of rotor.**
- **Considering the second-order sum-frequency wave load effects, the most dangerous condition for the ULS check for the critical section of DTU-10-MW reference wind turbine is shifted to the parked condition from the rated condition.**

## Acknowledgement and Contact


➢ *Acknowledgement*

- The support provided by China Scholarship Council (CSC) during a visit of Haozhe Bai to the Norwegian University of Science and Technology in Trondheim, Norway is acknowledged.
- The work is also supported by the Young Elite Scientists Sponsorship Program for doctoral student by CAST



➢ *Contact*

- ***Email: bhz@stu.ouc.edu.cn***


ResearchGate