Response Analysis of Monopile-Supported Large Offshore Wind Turbine under Wind, Wave, and Earthquake Loads

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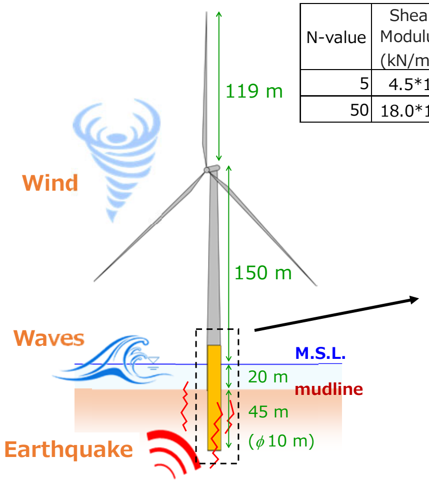
Introduction

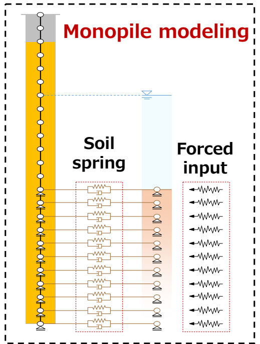
- Seismic evaluation of monopile-supported offshore wind turbines (OWTs) is essential in seismically active regions.
- Structural response assessments typically analyze wind and wave loads separately from seismic loads, combining the results to estimate the overall response[1].
- However, this approach overlooks the complex interactions among wind, wave, and seismic forces, which can significantly amplify the turbine's structural response, particularly in regions with high seismic risk and variable ground stiffness.
- This study investigates the response characteristics of monopile-supported OWT under wind, wave, and seismic loads through coupled load analysis.

Analysis outline

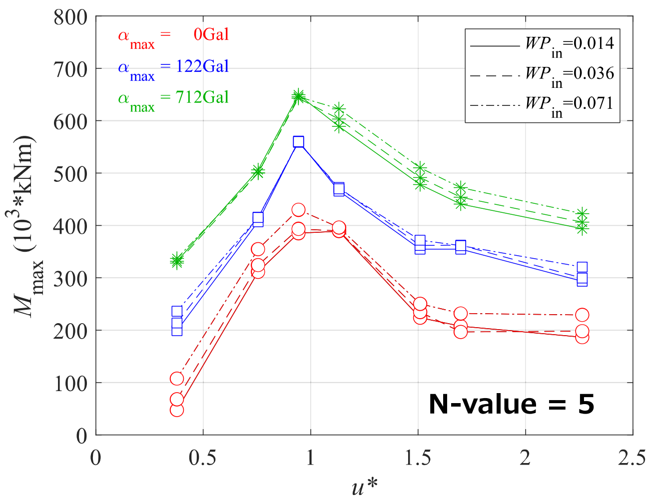
- A 15 MW monopile OWT model for IEA Wind TCP validation in coastal waters (h = 20 m), with the monopile embedded 45 m below the seabed.
- Modified OpenFAST-v3.0.0 code[2] including
  - ✓ **Soil-monopile interaction**: modeled using translational linear spring elements for linear interaction effects.
  - ✓ **Seismic forces**: applied as ground displacement, velocity, and acceleration derived from seismic response analysis
- Fluctuating wind (Kaimal spectrum)
- Irregular waves (JONSWAP spectrum)
- Soil conditions: N-values 5 and 50
- Maximum seismic accelerations a_{max}: 122 and 712 Gal
- Sampling frequency: 20 Hz
- Analysis duration: 600 s

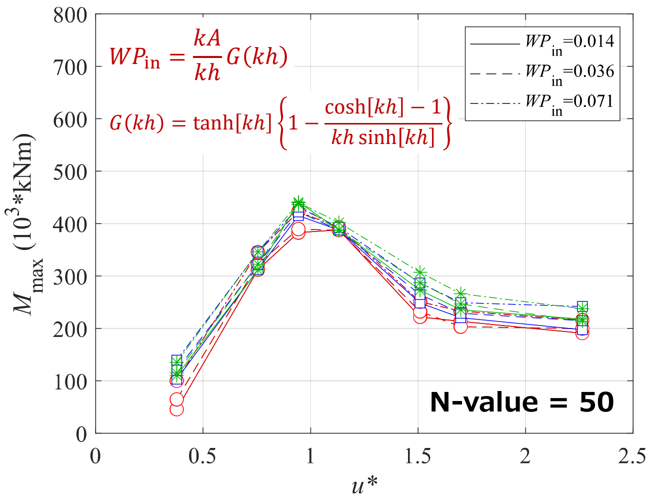
N-value	Shear Modulus (kN/m^2)	Poisson's ratio	Shear Wave Velocity (m/s)	Rayleigh damping
5	4.5*10^4	0.33	150	7.64*10^{-3}
50	18.0*10^4	0.33	300	3.82*10^{-3}





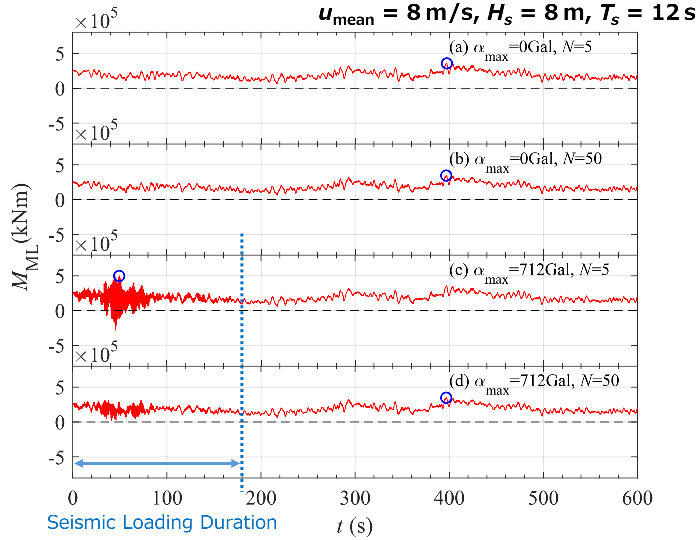
Relationship between u^* and M_{max}





- Relationship between hub-height mean wind speed u^* and maximum bending moment at the seabed M_{max} reflects the blade pitch control of wind turbine responses.
- For soil with N = 5, seismic forces amplify bending moments, especially at larger acceleration condition.
- In contrast, for stiff soil (N = 50), the rigidity transfers seismic energy directly to the support structure, making seismic effects on turbine response negligible
- This highlights the role of turbine response modes to wind, wave, and seismic forces.

Occurrence timing of M_{max}



- Under non-seismic conditions (a_{max} = 0 Gal), maximum responses occur simultaneously (t = 400 s), regardless of soil stiffness (Fig. (a) and (b)).
- With seismic forces, maximum responses occur during the earthquake for N = 5 soil and after it for N = 50 soil.
- This suggests that wind and wave effects, rather than seismic forces, may dominate the response depending on seismic acceleration and soil stiffness (Fig. (c) and (d)).
- Seismic impact is most significant under high seismic forces and low soil stiffness, influenced by the timing of external forces.

Conclusion

- The turbine's response is strongly influenced by the interaction between seismic forces and ground stiffness.
- High seismic forces combined with low ground stiffness notably amplify the response.
- The sensitivity to the timing of external forces underscores the need to consider these interactions in designing safer and more efficient turbines.

References

1. Committee on study of developing offshore wind power generation facilities: Official explanation of technological standards for offshore wind power facilities, (2020) p. 143.
2. Kashima, H., Takahashi, H., Ohya, Y. and Yoneyama, H.: Sensitivity analysis of offshore wind turbine response considering seismic forces in OpenFAST, *Proceedings of the 45th Japan Wind Energy Symposium* (2023).