Wind-Wave Directional Effects on Fatigue of Bottom-Fixed Offshore Wind Turbine

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Motivation

- Importance of wind-wave misalignment on fatigue damage is well known
- Effect of wave spreading is less known
- Assuming long-crested waves is shown conservative for a few isolated cases [1, 2]
- Deeper water and increased monopile diameter increases importance of wave loads and relevance of wave spreading
- Assuming long-crested waves may become non-conservative as wave loads become dominating

Method

- The DTU 10 MW reference turbine is placed on a monopile foundation
- Different wave sensitivity is modelled by altering the mode shapes
- Three soil stiffnesses analysed
- Natural period tuned to same value by varying wall thickness in tower
- All other design parameters kept unchanged

Models

- Variation in 1st and 2nd fore-aft mode shapes are shown in Fig. 1
- Equal natural frequencies achieved for first global modes
- 2nd modes are outside wave-frequency range

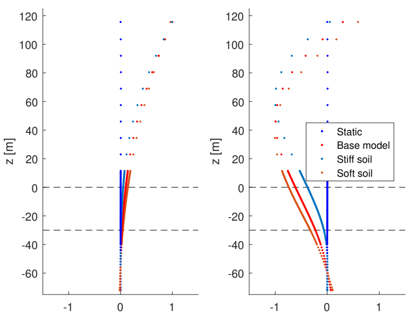

Figure 1: 1st (left) and 2nd (right) global fore-aft modes

Mode	Base model	Stiff soil	Soft soil
1st fore-aft	0.21 [Hz]	0.21 [Hz]	0.21 [Hz]
2nd fore-aft	1.05 [Hz]	1.30 [Hz]	0.97 [Hz]
1st side-side	0.21 [Hz]	0.21 [Hz]	0.21 [Hz]
2nd side-side	1.01 [Hz]	1.37 [Hz]	1.00 [Hz]

Lifetime fatigue analyses

- Lifetime fatigue damage calculated at most critical positions in monopile and tower
- Environmental data from Dogger Bank area
- Damage calculated for aligned wind and waves, as well as misaligned wind and waves with long-crested and short-crested waves
- DLC 1.2 and DLC 6.4 considered

Sensitivity to wind and wave loads

- Variations in the mode shapes will influence the importance of wind and wave loads for fatigue
- Sensitivity is illustrated by calculating fatigue damage assuming aligned wind and waves
- Contribution to lifetime fatigue damage per wind speed is shown for most critical position on monopile (Fig. 2) and tower (Fig. 3)

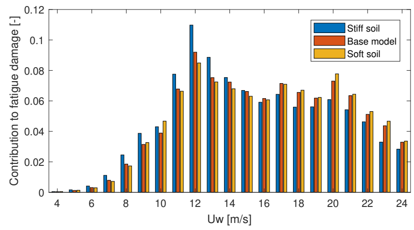

Figure 2: Monopile

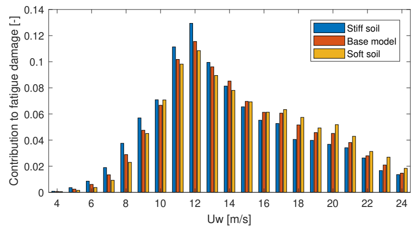

Figure 3: Tower

- Model with soft soil has a larger contribution to lifetime fatigue damage from wave loads. This corresponds to high wind speeds in Fig. 2 and 3
- Model with stiff soil has a larger contribution to lifetime fatigue damage from wind loads. This corresponds to wind speeds close to rated in Fig. 2 and 3

Effect of short-crested waves

- The lifetime fatigue damage is calculated assuming both long-crested and short-crested waves
- Wind-wave misalignment now taken into account

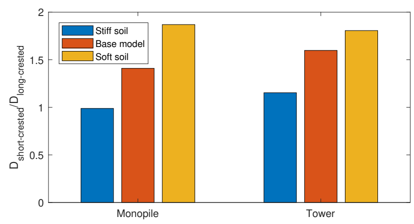

Figure 4: Ratio of maximum fatigue damage when assuming short-crested or long-crested waves

- Fig. 4 shows the effect of assuming short-crested or long-crested waves
- For all models, assuming short-crested waves increases the fatigue damage in the tower
- For the monopile, assuming long-crested waves is conservative only with the stiffest soil
- This is consistent with the reduced sensitivity to wave loads as the soil stiffness increases

Conclusion

- It may be both conservative and non-conservative to assume long-crested waves when designing offshore wind turbines
- As the sensitivity to wave loads increases, assuming long-crested waves becomes increasingly non-conservative

References

[1] Jan-Tore Horn, Jørgen R Krokstad, and Jørgen Amdahl. Long-term fatigue damage sensitivity to wave directionality in extra-large monopile foundations. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, 232(1):37–49, 2018.

[2] Jenny M. V. Trumars, Johan O. Jonsson, and Lars Bergdahl. The effect of wind and wave misalignment on the response of a wind turbine at Bockstigen. In *ASME 2006 25th International Conference on Offshore Mechanics and Arctic Engineering*, volume **1**. ASME, June 2006.

Acknowledgements

This work has been carried out at the Centre for Autonomous Marine Operations and Systems (NTNU AMOS). The Norwegian Research Council is acknowledged as the main sponsor of NTNU AMOS. This work was supported by the Research Council of Norway through the Centres of Excellence funding scheme, Project number 223254 - NTNU AMOS.