Fatigue life influence of damping and scour for monopile-supported offshore wind turbines

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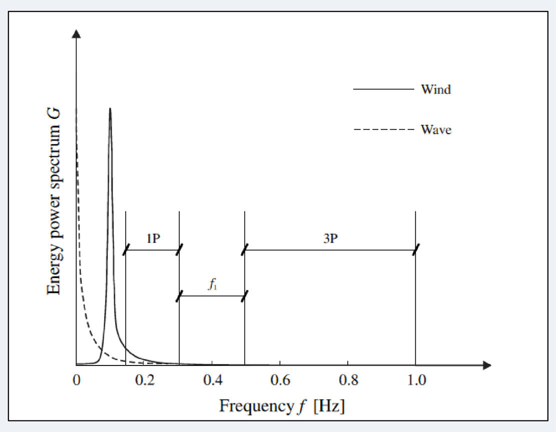
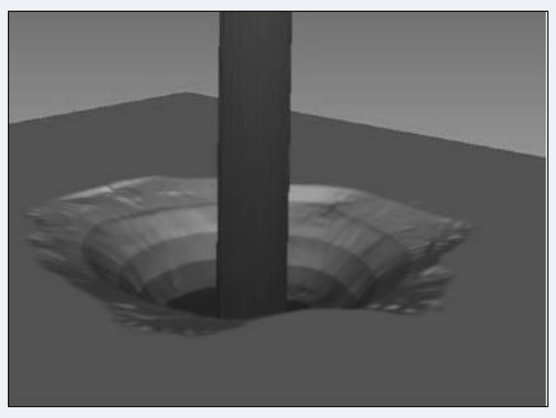
Research Objective

To study the sensitivity of the fatigue life of Offshore Wind Turbines (OWTs) mounted on monopiles to variations in scour and damping in view of improving their design.

Background

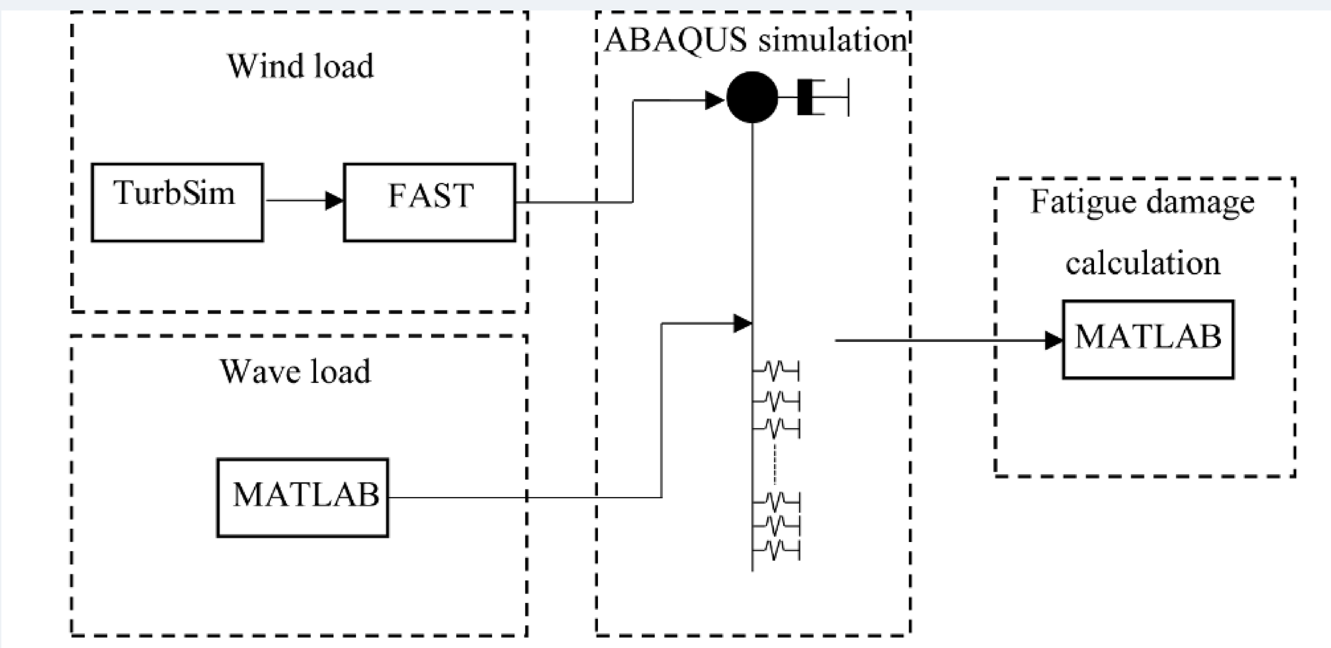
- Monopiles are currently the most common support structure for OWTs.
- To avoid resonance, the natural frequency of OWTs must be in a narrow range between the loading and blade passing frequencies.
- The dynamics of the system are mainly driven by damping and stiffness variations.
- Research has shown that there is a level of uncertainty around the total amount of damping (i.e. aerodynamic, soil, hydrodynamic, structural) in OWTs.
- Scour around monopiles has been shown to be variable. The influence of backfilling on the dynamic response of OWTs has received some attention.
- Detailed implications of damping and scour variations on the long-term vibration and fatigue life are yet to be determined.



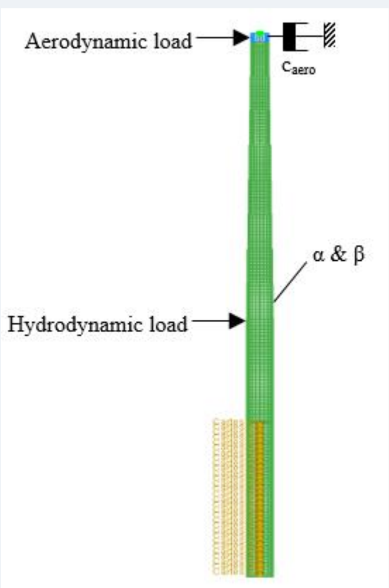


Methodology

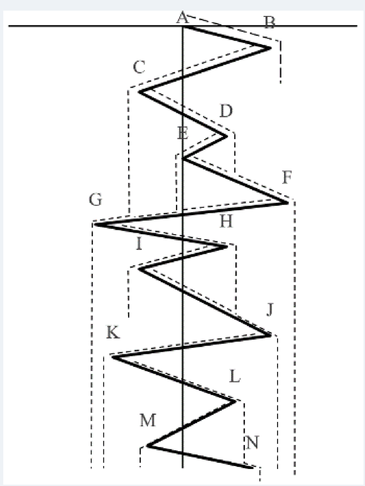
- NREL 5MW wind turbine is used as the reference model.
- Soil-structure interaction and transition piece influence on the static and dynamic responses of the OWT support-structure was studied using 3D solid element models.
- The complete fatigue analysis was carried out in different stages using a combination of software packages.



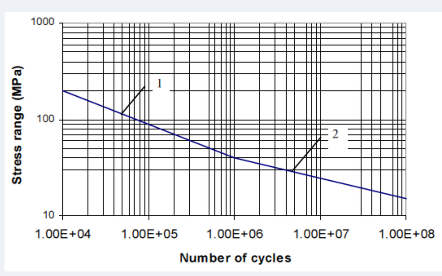
- Beam element model of the wind turbine with Winkler springs are used for the fatigue analysis.



Rainflow counting



S-N curve



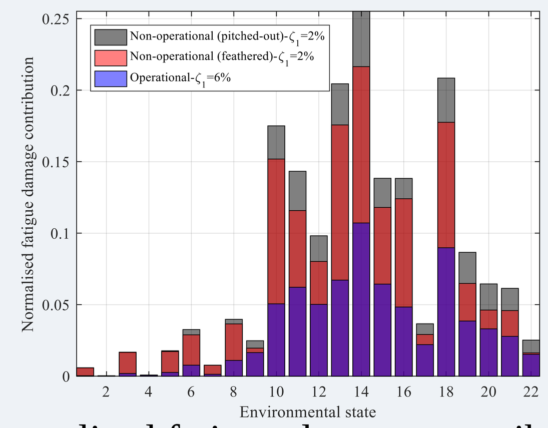
Palmgren-Miner rule

$$D_k = \frac{1}{\bar{a}_j}\sum_{i=1}^{N_c}\left[n_p \times \left(\Delta\sigma_{i(factored)}\right)^{m_j}\right]$$

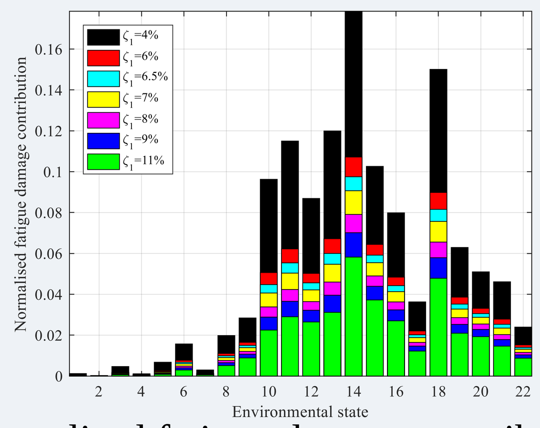
- Aerodynamic damping applied as a dashpot, damping from other sources incorporated as Rayleigh damping.
- Scour modelled by removing lateral springs (defined by p-y curves), backfilling considered by adding back springs with different stiffness.
- 22 environmental states are considered, which are within the operational range of the turbine.
- Turbine operational regime, variability of damping with wind speed, backfilled material density and backfilling period were also studied.

Key Findings

1. p-y curves show a slight over-estimation of stiffness compared to Mohr-Coulomb soil models with friction contact. OWT stiffness is not affected significantly by transition piece stiffness variations.
2. Damping influence
   - Aerodynamic damping compensates for the higher rotor loads in the operational wind turbine compared to the parked wind turbine.
   - Fatigue damage is significantly reduced for increased damping in the operational wind turbine.

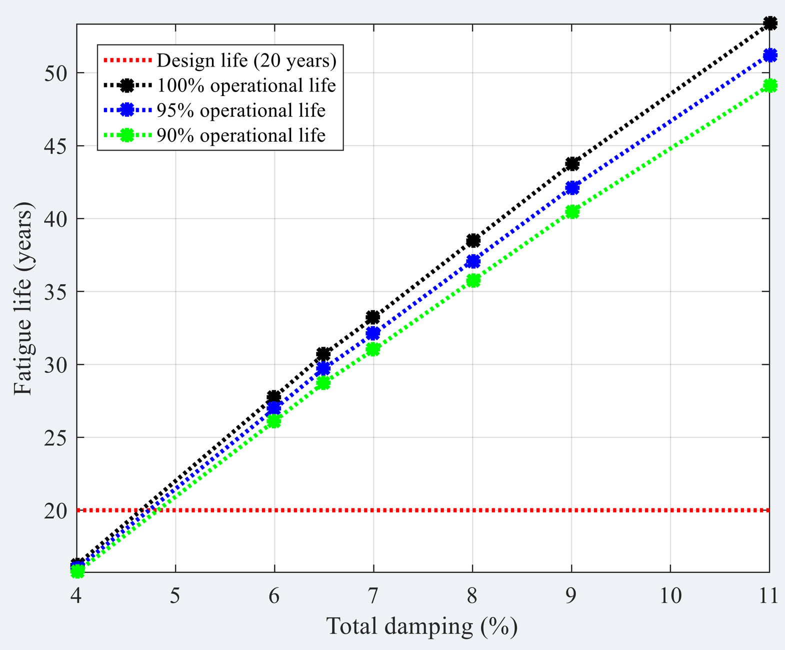


Normalised fatigue damage contribution of different environmental states for different operational regimes.



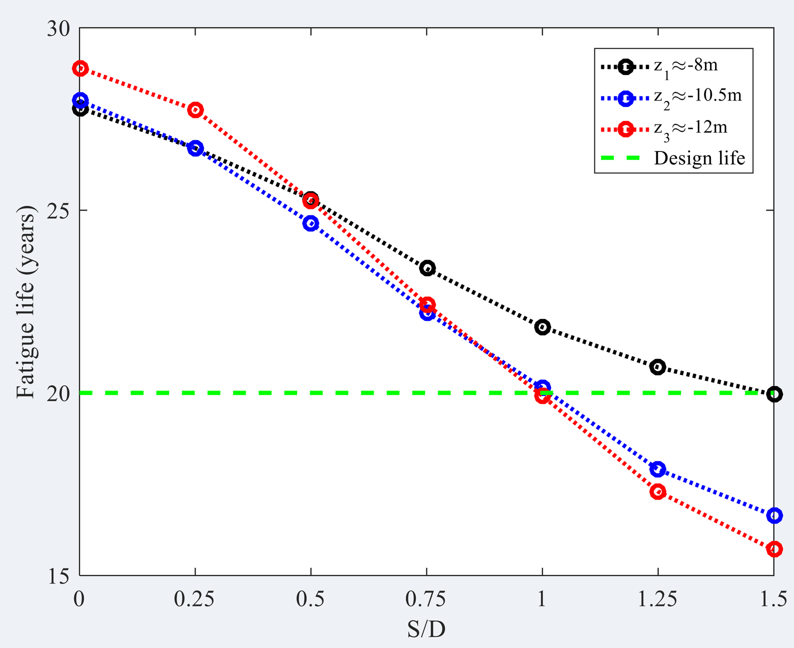
Normalised fatigue damage contributions of different environmental states for various damping levels.

- Variable damping application results in a change of less than 7% in the fatigue life.
- Fatigue life increases linearly from 16 years to 53 years as a result of 7% increase in damping.
- Good match found between steady-state and stochastic dynamic response stress variations. Simplified method is proposed for a faster fatigue life prediction of damping variations (added damping or uncertainties).



Fatigue life variation due to damping for various turbine shutdown periods.

3. Scour influence
   - The location of maximum bending moment moves down with scour depth.
   - Fatigue life reduces by up to 45% depending on the scour depth and the considered location along the monopile.
   - Fatigue life recovery due to backfilling is largely dependent on the backfilled period.



Fatigue life variations due to scour considered at different locations.

   - Comparison of static and dynamic responses of the OWT due to scour shows good match. A simplified method is proposed for the fatigue life estimation of scour/backfilling uncertainties based on the static analysis.

Conclusions

- Damping uncertainties have substantial implications on long-term performance.
- Fatigue life of OWTs can be extended, or stress demand can be reduced significantly by additional damping (e.g. tuned mass damper).
- Modal changes due to scour are typically small, fatigue life is mainly influenced by variations in the static and quasi-static response of OWT.
- Variation of maximum stress location due to scour must be considered in the fatigue design of OWTs.
- Backfilling in OWTs can lead to more economic fatigue design.