Simplified Fatigue Assessment of Offshore Wind Support Structures Accounting for Variations in a Farm

Vasileios Michalopoulous and Michiel Zaaijer
Delft University of Technology, Faculty of Aerospace

Abstract
The preliminary strength assessment of offshore wind support structures gains growing interest given the potential to drive the costs down [1] [2] [3]. This research develops a framework for Fatigue Limit State (FLS) estimations of monopiles in a simple manner to address site variations in an offshore wind farm (OWF). The framework consists of two elements: (i) a stand-alone model that predicts in a simplified way the damage caused by the varying loading and (ii) correction factors that escort element (i) and increase its reliability. The development of element (i) relies on the analytical approximation of the dynamic response of the system, thus by-passing time consuming numerical processes and advanced software. The method works well for lower parts of the support structure, making it suitable for monopile analysis and design.

Concept of FLS “Extrapolation”

Motivation
Impact of site variations (soil, bathymetry, wind / sea state) on the fatigue of monopiles within one OWF

Requirements
• Speed
• Reliability
• Suitability for the early design phase
• Extendable to yield tailored design solutions

Basic principles
• Developed method for quick FLS estimations (outlined in red) applied at any location in the OWF
• Calibration of this method at the reference position of the OWF
• Transfer of the correction factors, as derived by the calibration, to every new location at the OWF

Simplified FLS Assessment

Simplification of the conventional frequency-domain for fast FLS estimations:
• Isolation of the dynamic load components of the excitation
• Analytical calculation of the quasi-static response (wind+wave), by-passing the complicated derivation of a Transfer Function (TRF) [4]
• Application of a 1-degree of freedom Dynamic Amplification Factor (DAF) to derive the dynamic response

Validation: simplified FLS Assessment

Set-up specifications:
• Proposed Methodology (PM) vs Time-domain (TD)
• TD code: DNV-GL Bladed™
• Egmond aan Zee, NL
• Vestas V90
• 22 lumped environm. states (DLC 1-2, DLC 6-4)
• Wind-wave alignment
• Single-location application

Outcome:
+ Efficiency performance with global DEL errors <3%
+ Simulation time 5min
- Over-estimation of DEL at states 7 11 (around rated wind speed, moderate sea states)
- Under-estimation of DEL at states 14-22 (nominal power production, severe sea states)

Remarks:
• Well-matching PSD and captured trends
• Compensation between contradicting behaviours: over- and under-prediction
• Reduced accuracy due to smooth stress histograms produced by Dirlik method (PM), while rainbow counting (TD) induces spikes and troughs
• Necessity for the correction factors during FLS extrapolation

Case Study: FLS “Extrapolation”

Set-up specifications:
• Hornsea, UK
• NREL 5MW, conceptual farm layout
• Variations: water depth, soil profile, wind/sea state @ 4 locations
• Extrapolation with correction factors
• Comparison of results with DNV-GL Bladed™

Outcome:
+ Significant DEL errors (for early design phase) at elevations close to mudline: <5%
- Elevations at and above MSL imply low accuracy: ~20%

Ways of improvement identified and under implementation!

Conclusions
A scheme for quick FLS predictions is developed to investigate the site variations in an OWF. The core block of this method comprises a simplified and fast frequency-domain analysis which requires calibration at a reference position. The high reliability close to the mudline signifies its suitability for preliminary optimisation of particularity the foundation piles at several locations of an OWF.

References