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Assessment of the state-of-the-art ULS design procedure for offshore wind turbine sub-structures

Hübler, C. | Gebhardt, C. G. | Rolfes, R.
Institute of Structural Analysis, Leibniz Universität Hannover
c.huebler@isd.uni-hannover.de

Abstract

Sub-structures of offshore wind turbines are designed according to several design load cases (DLCs). These DLCs are given in the current standards, and are supposed, on the one hand, to cover accurately all significant load conditions to guarantee reliability. On the other hand, they should include only necessary conditions. **Here, for ULS conditions, the question whether the current design practice is, firstly, sufficient, and secondly, sensible concerning the computing time by only including necessary DLCs is addressed.** Probabilistic simulation data of five years of normal operation is used to extrapolate 20-year ULS loads (comparable to a probabilistic version of DLC 1.1 for sub-structures). These ULS values are compared to several deterministic DLCs required by current standards (e.g. DLC 6.1). Results show that probabilistic, extrapolated ULS values can exceed standard DLC-loads. Hence, the current design practice might not always be conservative. Especially, the benefit of an additional DLC for wave peak periods close to the eigenfrequency of the sub-structure is indicated.

Simulation setup

For all time domain simulations, the FASTv8 code is used. A soil model applying soil-structure interaction matrices enhances the FASTv8 code [1]. The NREL 5MW reference turbine with the OC3 monopile is investigated.
For the probabilistic approach, statistical distributions for environmental conditions were derived using the FINO3 data (North Sea) [2]. For the DLC-based approach, extreme values are derived here using the same data.
For the ULS analysis several limit states, including the plastic limit state and the buckling limit state for the monopole, are used to calculate utilization factors (UFs). Additionally, ULS proofs for the foundation piles are performed according to GEO2. Aging effects etc. are not taken into account.

ULS calculation

DLC-based approach

The DLC-based approach is uses extreme environmental conditions, e.g. the 50 year storm. Hence, extreme values are derived using 4-week maxima that are directly extracted from the data. Fig. 1 illustrates this process for DLC 6.1. 4-week maxima are extracted for the wind speed, but for the turbulence intensity only the corresponding values are used. These values are not the maxima, as the highest turbulence does not coincide with extreme wind speeds. Statistical distributions are fitted to the 4-week maxima (or there corresponding values) using a maximum likelihood estimation (MLE). Having determined a statistical distribution, the values corresponding to a recurrence period of 50 years can be determined (see Fig. 1).

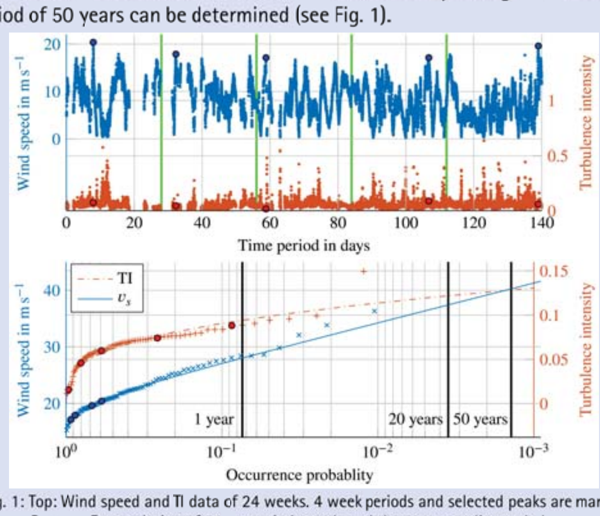

Fig. 1: Top: Wind speed and TI data of 24 weeks. 4 week periods and selected peaks are marked
Bottom: Extrapolation of 50-year wind speeds and the corresponding turbulence

Probabilistic approach

A possible addition to the deterministic DLC-based approach that takes scattering conditions into account is a probabilistic or Monte Carlo simulation approach. Environmental conditions are sampled according to their depending distributions to enable a simulation of 5 years of realistic lifetime (~250000 samples) including unfavourable, but realistic parameter combinations. An extrapolation to 20 years of operation is possible by fitting distributions to the extracted peaks (maxima of all simulations). For the fit, an MLE and only the highest utilisation factors (tail fitting) are used.

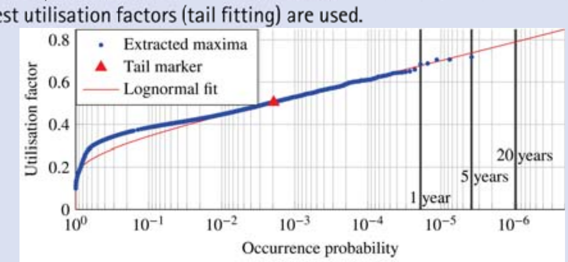

Fig. 2: UFs of all probabilistic simulations (5 years): lognormal tail fit for 20-year extrapolation

Results

In Fig. 3, the DLC-based approach is compared to the probabilistic one. For the DLCs, mean and maximum values (error bars) of 100 DLC simulations are shown. For the probabilistic approach, 1-year, 5-year, and 20-year values are displayed. The 5-year value is the maximum UF of all simulations, while 1 and 20-year values are based on bootstrap samples (and an extrapolation for the 20-year value). The probabilistic approach leads to the highest ULS loads. As these loads exceed the ULS values of the DLC-based approach for the 5-year value, this fact is independent of the extrapolation technique. Most of the extreme UFs occur at wave periods of around 4s being close to the resonance frequency of the monopile. Hence, the probabilistic approach reveals the fact that wave resonance might be a problem for monopiles with larger diameters. Wave resonance is not covered sufficiently by the DLC-based approach, as deterministic wave periods are assumed.

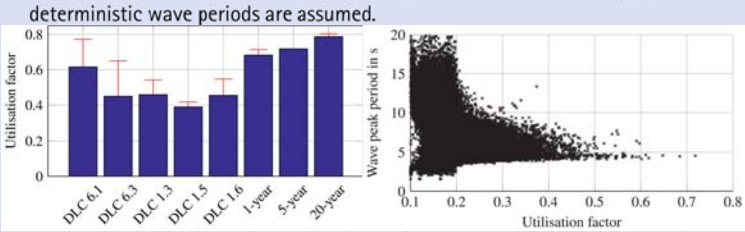

Fig. 3: Left: Comparison of UFs; Right: Investigation of high UFs for the probabilistic approach

Conclusion and Outlook

Results show that - independent of the load extrapolation technique - probabilistic, extrapolated ULS values can exceed the deterministic 50-year ULS loads of the standard DLCs. Therefore, for sub-structures, the current DLCs (excluding fault cases etc.) might not be always conservative. The extrapolation of loads in power production can lead to higher loads, if a probabilistic approach is applied.
In the long term, a reconsideration of DLCs might be valuable. Some load cases can perhaps be removed; others, like a DLC for wave resonance problems, might be missing. Still, due to the limitation of this work to simplified models (FASTv8), sub-structures, no fault cases etc. an exclusion of DLCs based on this work would be premature.

References

[1] Häfele J, Hübler C, Gebhardt CG, Rolfes R. An improved two-step soil-structure interaction modeling method for dynamical analyses of offshore wind turbines. Applied Ocean Research 2016; 55: 141-150.
[2] Hübler C, Gebhardt CG, Rolfes R. Development of a comprehensive database of scattering environmental conditions for offshore wind turbines. Wind Energy Science 2017; 2: 491-505.

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