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Polymorphic uncertainty in met-ocean conditions and the influence on fatigue loads

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Abstract

An accurate simulation of the fatigue lifetime of offshore wind turbines is a challenging task, e.g. due to the uncertainty of met-ocean conditions (wind and waves). This uncertainty can be divided into aleatory and epistemic uncertainty. According to the state of the art, for met-ocean conditions, mainly aleatory uncertainty is considered. This leads to a simplification, whose effect on the lifetime estimation has not been analysed so far. In that sense, here, the influence of various uncertainty models for met-ocean conditions on long-term damage equivalent loads (DELs) is investigated. Not only purely probabilistic models are applied, but interval random variables (i.e. p-boxes) as well. It is shown that uncertainty models have a considerable influence on the fatigue life.

Uncertainty models

For the formulation of different uncertainty models for wind speed, wave height, and wave period, real offshore measurement data (FINO3 data) is used. A representation of the measurement data can be seen in Figure 1.

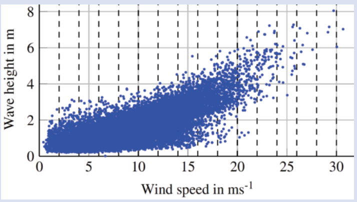

Figure 1: Scattering met-ocean data measured at the met-mast FINO 3 in the North Sea

The data is highly correlated. As a consequence, the original data is clustered in bins (indicated in Figure 1 for the wind speed by dashed lines) to remove the correlation within each bin. In each bin, empirical and best fitting theoretical (e.g. Weibull for wind speed) distributions are determined, see Figure 2.

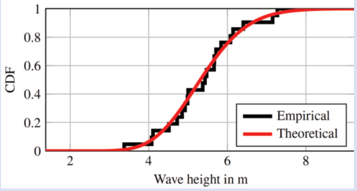

Figure 2: Pure probabilistic CDFs for wave height and wind speeds between 22 and 24 ms^{-1}

The empirical CDF in Figure 2 demonstrates the scarcity of data within some bins. As a result, it is no longer justified to assume the statistical uncertainty to be negligible. Hence, intervals are defined [1]. The resulting distributions are shown in Figure 3.

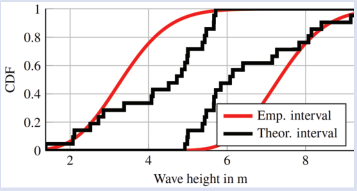

Figure 3: Interval CDFs for wave height and wind speeds between 22 and 24 ms^{-1}

After having determined uncertainty models for met-ocean conditions (inputs), the main challenge is to calculate minimum and maximum values for DELs (output), since any input values within the input interval can lead to minimum and maximum outputs (e.g. a high wave period does not necessarily yield high DELs). We apply global optimisation to find the required values.

Fatigue calculation

The fatigue calculation is conducted for the NREL 5MW reference wind turbine [2] with a monopile as substructure. As a measure for fatigue, we exemplarily apply lifetime DELs [3] for the overturning moment in wind direction at mudline. Since the computation of lifetime DELs using aero-elastic simulation codes, here FAST, is quite time-consuming, we utilise a meta-model-based approach, which correlates polymorphic uncertain met-ocean conditions to short-term DELs. The meta-model applied is a Kriging model with a linear basis function and a squared exponential covariance function. It is fitted based on 5000 training data points and validated based on another 5000 test data points (see Figure 4).

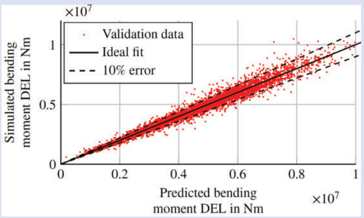

Figure 4: Visual validation of the Kriging model: Kriging prediction vs. aero-elastic simulation results

Results

For each uncertainty models, lifetime DELs (or lifetime DEL intervals) are calculated. The results are summarised in Table 1. The consideration of polymorphic uncertainty yields wide ranges of lifetime DELs. Hence, it can be suspected that lifetime DELs exhibit a relevant amount of uncertainty that is not detected by pure probabilistic approaches.

Uncertainty model	Mean lifetime DEL	Lower bound	Upper bound
Empirical CDFs	5.286 MNm	---	---
Theoretical CDFs	5.287 MNm	---	---
Emp. interval-CDFs	---	4.924 MNm	5.839 MNm
Theor. interval-CDFs	---	4.775 MNm	5.995 MNm

Table 1: Lifetime DELs for different uncertainty models

Conclusion and Outlook

The results of this study suggest that the consideration of statistical uncertainty by applying interval random variables yields large ranges of lifetime DELs. This clarifies the existing uncertainty in fatigue loads that is neglected by using pure probabilistic approaches. Hence, probabilistic approaches can under- and overestimate the real fatigue lifetime of offshore wind turbines.
Future work should address the inclusion of the meta-model uncertainty (cf. Figure 4) and fuzzy random uncertainty models. Finally, it might be useful to improve the efficiency of optimisation process for the interval variables.

References

[1] Zhang H, Dai H, Beer M and Wang W 2013. Structural reliability analysis on the basis of small samples: an interval quasi-Monte Carlo method. Mechanical Systems and Signal Processing 37 137-151.
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