Probabilistic fatigue design of jacket support structures for offshore wind turbines exemplified on tubular joints

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Motivation

Jackets are commonly used substructures for offshore wind turbines with a rated power of at least 5 MW for sites with water depths greater 25 m. During their life time, offshore wind turbines and the substructures are stressed by fatigue loads caused by wind, operation and sea state. The welded tubular joints of jackets are highly stressed due to their complex geometry. This work addresses the stochastical representation of fatigue resistance and fatigue loads, where especially the very high, rarely occurring loads that are decisive for the fatigue design are a point of interest. Using adequate probabilistic methods, advanced structural design of offshore wind turbines shall be found in order to improve safety and reduce costs.

Probabilistic safety concept

- All possible scenarios in life time have to be considered.
- Load effects, loads, and resistance are represented by their respective probability distributions.
- Target probability of failure is set in accordance to required safety class.

<u>Fatigue design</u>

- Scattering of stress ranges *Δσ* and of fatigue resistance (detail category $\Delta\sigma_c$) for all load effects during the considered life time *t*
- Scattering of critical fatigue damage D_{cr}

$$D_{fat} = \int_{life\ time} \iint \frac{n \cdot f(\Delta\sigma, t)}{N(\Delta\sigma \mid \Delta\sigma_c, t)} \cdot f(\Delta\sigma_c, t) \cdot d\Delta\sigma \cdot d\Delta\sigma_c \cdot dt \leq D_{cr}$$

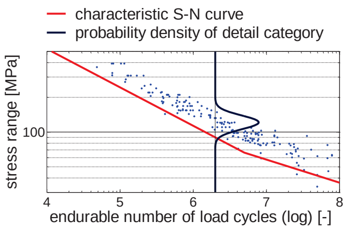

Fig. 1: Probability distribution of fatigue resistance

Representation of very high fatigue loads

- Only 10 up to 15 values per 1-hour time series can be used for adequate stochastical description of very high stress ranges.

<u>Peak-over-threshold method</u>

- Suitable for tail estimation of an empirical distribution of random values
- Values above a certain threshold *u* are described by the generalized Pareto distribution.

$$f^{GPD}_{\xi,\beta,u}(x) = \begin{cases} \frac{1}{\beta} \cdot \left(1 + \xi \cdot \frac{x-u}{\beta}\right)^{-\frac{\xi+1}{\xi}} & if\ \xi \neq 0 \\ \frac{1}{\beta} \cdot \exp\left(-\frac{x-u}{\beta}\right) & if\ \xi = 0 \end{cases}$$

- Parameters of generalized Pareto distribution are found by applying the maximum-likelihood estimation method (goodness-of-fit test).

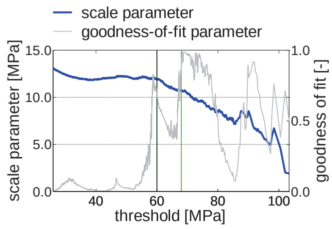

Fig. 3: Calculated scale parameter over threshold

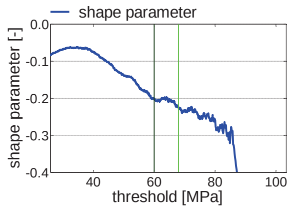

Fig. 4: Calculated shape parameter over threshold

Statistics of fatigue loads and fatigue damage

- Fatigue loads at K-joints are given on basis of numerical simulations of offshore wind turbine with jacket substructure effected by turbulent wind and irregular sea state.
- 53 one-hour time series of one load scenario with constant parameters for wind field and sea state are evaluated.

<u>Semi-probabilistic safety concept:</u>

- Scattering of fatigue damage for 53 different time series:
  - in range of -26% up to +46%, relative to mean value
  - coefficent of variance: 18%
- The highest 5% of fatigue loads account for 75% of fatigue damage

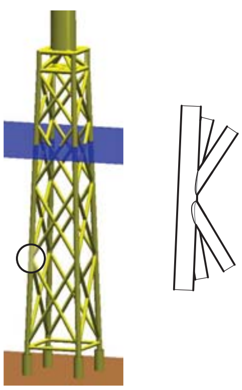

Fig. 2: Investigated jacket and K-joint

Probabilistic fatigue design

- Probability of failure differs with respect to chosen threshold.

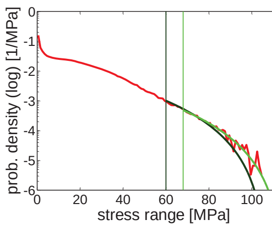

Fig. 5: Probability distribution of fatigue loads (empirical and analytical)

- Fatigue damage and probability of failure, relative to semi-probabilistic design

analysis with	relative damage	prob. of failure
empirical values	0.155	$3.57 \cdot 10^{-4}$
… and GPD	0.117	$4.13 \cdot 10^{-5}$
… and GPD	0.128	$8.75 \cdot 10^{-5}$

Acknowledgements

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Conclusions

- Very high stress ranges are important for structural design of substructures for offshore wind turbines.
- Probability of failure is reduced in comparison to semi-probabilistic safety concept.
- However, many simulations are required when applying probabilistic safety concept.

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