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Publication date:
2019

Document Version:
Final published version

Link to publication

Citation for published version (APA):

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Output based methods for in-situ fatigue monitoring for design optimization and life time extension of monopile foundations

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Abstract

Fatigue loading of offshore wind turbines is an interaction of wave loads, wind loads and the first structural modes of a wind turbine substructure. The design of offshore wind turbines on monopile (MP) foundation is driven by the fatigue life of the welded connections in the MP. As a result of design optimization typically the first welds beneath the sea bed are most fatigue critical and determine the lifetime of the offshore wind turbine. Accurate information about damage progress is essential for O&M strategies but also for further design optimization while both visual inspections and sensor installation are not favorable for those locations.

.“Measuring loads directly on the monopile will not be feasible for existing offshore wind turbines, therefore virtual sensing can be used.”

Monopole strain monitoring

Three monopiles at the Nobelwind offshore wind farm were instrumented with an array of optical fiber strain gauge sensors. This offers the possibility to measure the strain on the most fatigue critical locations on the monopole. These measurements will be used to validate the concepts of virtual sensing.

Virtual sensing: Concept

Virtual sensing estimates strain history of different locations on the monopole based on output measurements in easily accessible locations i.e. turbine tower. Unlike a digital twin, virtual sensing will not require any additional simulations or a detailed model. Virtual sensing uses dynamic response measurements to compose virtual measurements. By starting from response measurement the method inherently captures the interaction between wind and wave loads and the dynamic offshore wind turbine.

Estimation consists of quasi-static and dynamic band. First combines a SG sensor with the static deflection of the turbine and latter ACC sensors with the dynamic modes. It is already successfully applied to the welds of offshore wind turbines on monopiles substructures for locations above water.

As a benchmark the DEL extrapolation method is used. This method relates the recorded damage of a single SG sensor level to another. This DEL ratio between measurement and virtual location is determined over various conditions during a training period. In this research the DEL ratio is trained with measurement data.

Results

Over a period of 30 days virtual sensing and the DEL extrapolation method are tested thus their performance over many different operational and environmental conditions are analyzed. This virtual sensing approach uses mode shapes obtained from 7d of measurements while the competing method is trained with data of the 30d previous validation period. In a first step strain history is generated for every 10min condition via virtual sensing(right). The PSD shows a good fit of the estimation in the quasi-static band and for the first two dynamic modes. In time domain a time delay becomes apparent which is likely due to damping.

Subsequently, DELs are calculated from time history assuming linear damage. Results are compared to the direct DEL extrapolation showing very similar accuracy of both methods in estimating DELs of a subsoil location (left). On average an error of 5% occurs for the virtual sensing approach while the error is slightly smaller for the DEL extrapolation method. However accuracy appeared to depend noticeable from the training period.

Conclusions and Future work

Two fast, easy to implement, reliable and effective technique for output based fatigue prediction and life-time assessment from a limited number of sensors are introduced. The algorithms are validated using 30d of measurement data obtained from a monitoring campaign on a monopile foundation in the Belgian North Sea. During the benchmarking both methods showed the ability to predict subsoil fatigue accurately.

The availability of subsoil data within this project is exceptional. Commonly mode shapes for virtual sensing and the transfer function of DEL extrapolation methods will be trained with FE data. It is desired to evaluate the influence of such an approach. Furthermore, it is envisioned to extend the validation period to analyze influence of time varying effects e.g. scouring. Therefore virtual sensing will be integrated in a model updating scheme. Within the continued work on virtual sensing adaptations of the method will be considered to better deal with subsoil-damping and uncertainties in the mode shapes.

References

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