Offshore & Dredging Engineering

Technische Universiteit Delft

Combined Wind and Wave Loads for Fatigue Analysis in the Frequency Domain

The potential of offshore wind is enormous. The wind resource offshore is generally much greater than onshore, especially at bigger water depths. Expanding prudently into the sea leads to bigger support structures for the wind turbine. Therefore, the need for optimized designs, which will establish the wind energy as a low-cost solution, emerges. Structural optimization requires insight in the critical loads to which the wind turbines are subjected. The complex systems of variable loads render fatigue determinant for the life-span of the structure. However, a fatigue assessment requires computationally expensive time-domain simulations, which are the main obstacle for the optimization process. In conjunction with established work, this thesis aims at determining the accuracy of a fast frequency-domain model for fatigue loads estimation.

The overall goal of this thesis is to calculate the structural response to combined wind and wave loads in the frequency domain. The modeling of the wind loads and, more specifically, the modeling of the thrust force constituted the main scope of the current research. In order to calculate the response of the structure in terms of internal loads, a linear structural model with a lumped mass is used. A first qualitative assessment is made on the basis of power spectral densities. Dirlik's approach is used to translate the information hold in the PSDs into damage equivalent loads. Finally, the accuracy of the developed model was compared to relevant results derived with the time-domain aeroelastic software BHawC.
The developed model for wind loads calculation is incorporated into an existing frequency-domain tool for the estimation of the structural response to the wave loads. The accuracy of the response to wave loads only is satisfactory, with few sea states introducing errors in the range of 15%-20%. Less accuracy is demonstrated for the wave loads combined with a steady wind. Based on this case, some initial observations are made regarding the coupled dynamics of the offshore wind turbine which highlight the importance of the aerodynamic damping and the controller's action. Regarding the main goal of this study, a rotationally sampled turbulence spectrum is modeled. It is shown that a complete frequency domain based method proves to be cumbersome for the calculation of the thrust force.

The highly non-linear dynamic effects introduced by the controller's action is a proven limitation according to existing literature. Based on this fact, a quasi-static approach is used which considers unstalled conditions and assumes the pitch angle to be constant in a turbulent environment. As a result, errors up to almost 60% for the fatigue moments at the foundation are introduced, compared to results obtained with the time-domain simulations. Finally, the response to the combined loads are examined. The lower elevations of a monopile structure are wave driven while the wind loads are dominating at elevations closer to the hub. As a matter of fact, for aligned wind and waves, an accuracy of almost 82% is attained at the mudline due to the reliable wave model while the errors are considerably increased for higher elevations.

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