Corrosion-fatigue in offshore wind turbine sub-structures

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Motivation

In 2020, there were four Belgian offshore wind farms (C-Power, Northwind, Belwind and Nobelwind) producing 871 megawatts of power. Other projects are ongoing and planned to increase that capacity to 4 gigawatts by 2030. This strategy clearly emphasizes the support of the Belgian government for offshore wind as an important energy supplier for the future.

The Belgian wind parks and their wind turbine structures have different lifetimes. The oldest Belgian offshore wind farm, is in operation since September 2013. The steel support structures (jackets and monopiles) are subjected to both fatigue and corrosion, impacting their lifetime. Sound lifetime assessment tools are required to ensure the good and safe functioning of the wind turbines and secure the energy supply. These can help offshore wind farm owners and operators to optimize the wind farm, eventually lowering the Levelized Cost of Energy (LCoE). This is of importance for the farms that are currently in operation and need an optimized maintenance strategy and possible extension of their exploitation, as well as for new projects which can also benefit from lifetime assessment tools in the design process.

The low accessibility and high inspection/repair costs of large structures in corrosive environments is motivating remote monitoring and optimized inspection and maintenance plans, based on continuous assessment of the structural reliability.

Figure 1: Wind turbines in the Belgian offshore wind farms.

Due to the time-variant uncertainties associated with the environmental and mechanical loads, having reliable models that can predict the degradations due to corrosion and fatigue is necessary to assess the structural safety and to support decision making.

Objectives

The following objectives to tackle some fundamental knowledge gaps have been assigned to UGent:

1. Development of an advanced corrosion-fatigue model to analyze the interactive effects of corrosion and fatigue load on lifetime of welded joints. This necessitates the development and integration of models for pitting corrosion, short crack propagation and long crack propagation.
2. Implementing the integrated numerical framework to develop smart S-N curves that take into account the level of corrosion and presence of cracks to predict

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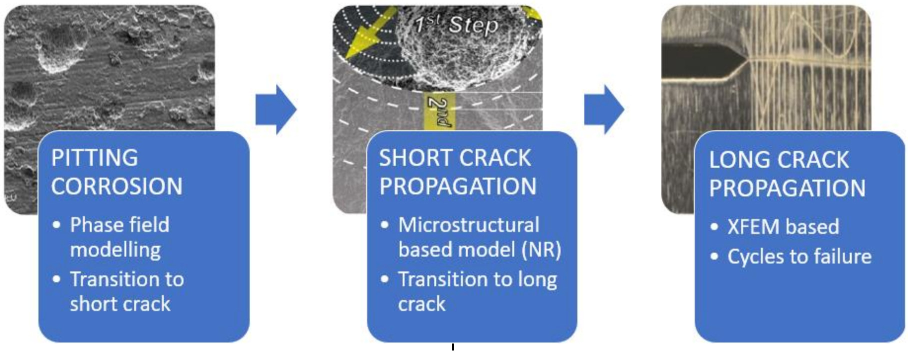

Figure 2: Three stages of modelling corrosion fatigue

the remaining life-time of offshore wind turbine sub-structures.

Approach

Providing efficient tools to estimate the remaining lifetime of offshore wind turbine structures more accurately, evokes the necessity of establishing new methods and approaches. A chain of phenomena must be investigated to recognize the most effective parameters on the lifetime of the structures. Offshore wind foundations are subjected to fluctuating mechanical loads (wind, waves, turbine) and operate in the harsh marine environment. The interaction between (pitting) corrosion and fatigue will significantly impact a foundation's lifetime.

This project will study these mechanisms at three levels. First the occurrence and growth of corrosion pits. Second the transition from a pit to a short crack and short crack growth. Third the transition from short to long crack and long crack propagation until failure. Different types of advanced numerical techniques will be employed.

At the first level, a phase-field method will be coupled with smoothed boundary method to simulate the pitting corrosion via constrained decrease of free energy determined by electrochemical kinetics at the metal/electrolyte interface. The metal and electrolyte domain evolve according to the advective Cahn-Hilliard equation and considering the dissolution and transport of ionic species.

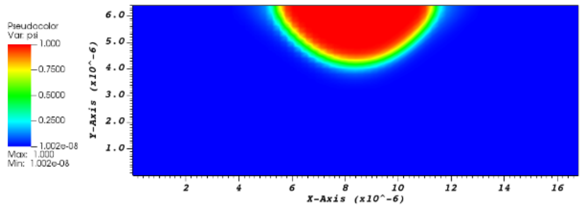

Figure 3: Simulation of a corrosion pit using phase-field

At the second level, a microstructural short crack model (NR model) will be used to simulate the short crack propagation. The NR model considers the crack and microstructural barriers by means of the distributed dislocation technique. It uses the Kitagawa-Takahashi diagram to account for the effect of the environment on the material's resistance for crack propagation.

At the third level, XFEM will be used to simulate the crack propagation from the moment the short crack reaches a critical length and becomes a long crack. Combining the models at these three levels should allow to predict the total lifetime of a structure on the one hand and to develop the aforementioned smart S-N curves on the other hand.

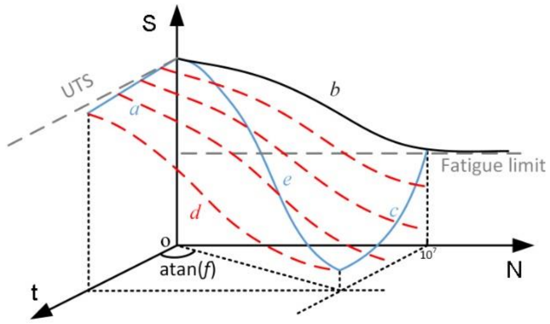

Figure 4: 3D smart S-N curves having time-dependent corrosion as third dimension

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