Digital twins-enabled probabilistic deterioration assessment of floating offshore wind turbine towers under uncertainties

Heng, Junlin; Zhang, Jiaxin; Dong, You; Kaewunruen, Sakdirat; Baniotopoulos, Charalampos

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Junlin Heng[1,2], Jiaxin Zhang[3], You Dong[3], Sakdirat Kaewunruen[2], Charalampos Baniotopoulos[2]*
[1] Shenzhen University, China, [2] University of Birmingham, United Kingdom, [3] The Hong Kong Polytechnical University, China
* j.l.heng@outlook.com

Summary The novel concept of modular energy islands comes with novels challenges, i.e., the coupled corrosion fatigue (CF) deterioration of floating wind turbine towers (FOWTTs). This work proposes a digital twins-based assessment approach to elucidate the CF feature of FOWTTs under uncertainties, by integrating both the site loads, material data, deterioration model and numerical simulation. The output highlights the notable C-F issue in FOWTTs, and offers basis for condition-based management.

Introduction

The emerging climate challenges and energy crisis have imposed urgent and heavy demands for a green and sustainable world with renewable and reliable energy supplies. The concept of modular energy island (MEI) [1] has been proposed to fully exploit the abundant natural powers at deep-water oceans, including wind, tidal, solar and other energies. The novel application also leads to novel engineering challenges. Especially, the massive high-strength bolts in ring-flange connections of wind turbine towers become highly prone to deterioration under coupling effect of dynamic loads-induced fatigue and marine corrosion, i.e., corrosion-fatigue (CF) [2]. The work aims to offer novel insights into the C-F deterioration of bolts in floating wind turbine towers (FOWTTs) on the MEI, by integrating the material test data, site-specific condition, probabilistic CF (PCF) model and multi-physics simulation

Methodology

The wind-wave data measured from the Mexico Gulf [3] are incorporated into the multi-physics simulation tool OpenFAST [4] to derive fatigue stress spectra in bolts, *see* Fig. 1. The spectra and climate conditions are processed by a PCF model [5], by which the deterioration evolution is estimated.

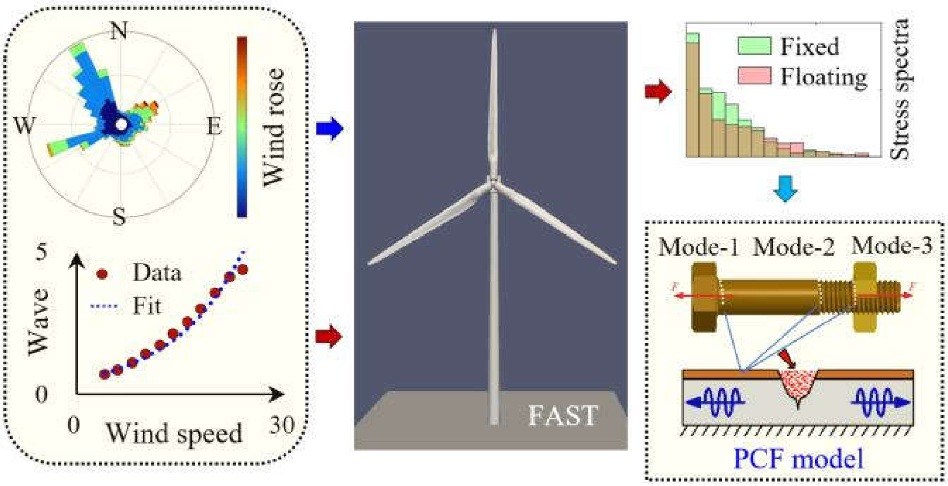

Fig. 1. Procedures for the probabilistic assessment of deterioration states using site data

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Results

Fig. 2 shows the evolution of fatigue crack growth, and the failure mode of the most critical bolt at the bottom flange. The model-3 (first engaged threads) demonstrates a high priority while the other two modes also have considerable contributions to the failure of bolts.

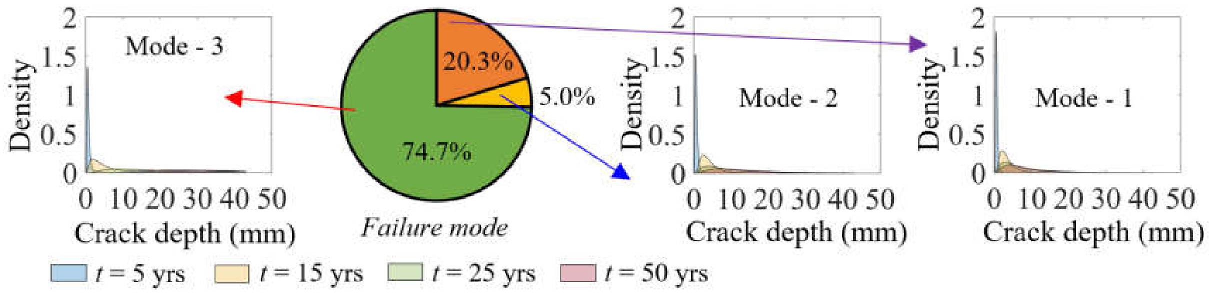
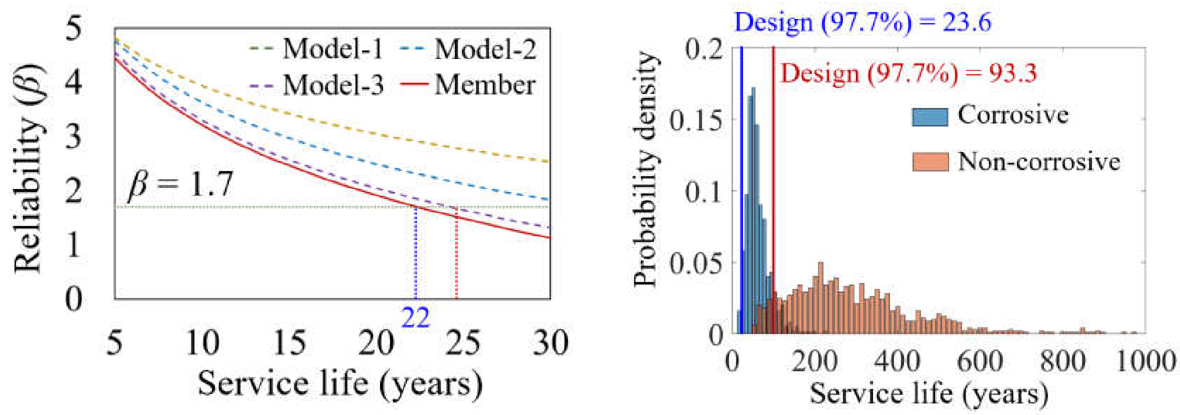


Fig. 2. Fatigue crack depth growth and failure modes of the most critical bolt in ring-flanges.

Fig. 3 shows the deterioration evolution of the above crucial bolts. The result suggests a premature failure risk (at 22 years) of bolts at the given marine condition under the target reliability of 1.7.



(a) (b)

Fig. 3. Deterioration evolution of the most critical bolt: (a) Reliability; (b) Life distribution.

Conclusions

(1) The high-strength bolt in ring-flanges of FOWTTs shows 3 major failure mode under CF, while the first engaged thread has the highest possibility. In both modes, the distribution of crack depth levels off and accumulates at the size threshold (i.e., 46.8 mm) with the service life.

(2) The strong marine corrosion risks premature failure of bolts since it fails to meet the design reliability index of 1.7. Particular efforts are suggested for bolts in FOWTTs.

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