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Toward a two-scale modeling of spiral strand wire rope for floating offshore wind turbine to predict fatigue damages: possibilities and difficulties in using a legacy code

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Summary: Mooring systems of offshore wind turbines have to be designed to resist cyclic tension and bending. In order to take into account bending for the computation of the fatigue damage, local phenomena of fretting have to be properly predicted by means of a new numerical model.

Introduction

In the wind energy context, a recent development area aims to extend the wind site possibilities by means of floating offshore wind turbines. These structures are basically constituted by a wind turbine installed on a floater, which is linked to the sea bed by means of mooring lines. The mooring system ensures the structure reliability by limiting the floater movement.

We consider a case study of a semi-submersible floater equipped with a redundant mooring system of six catenary mooring lines. These are constituted by spiral strands (Figure 1), whose design must consider extreme and fatigue loading, leading to combined tension and bending stresses induced by the floater movements for various wind and waves conditions.

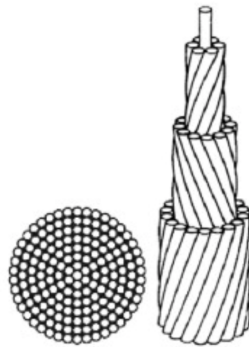


Figure 1: Spiral strand wire rope.

Wire rope behavior

During bending, relative movements among the wires take place, with consequent friction due to tension. Results from free-bending fatigue tests show the importance of these effects, since the first rupture is localized in correspondence with the bending neutral axis, where relative movements are larger [1].

Proposed approach

A global analysis alone is not sufficient to characterize and quantify the local fretting phenomenon. The proposed approach involves two scales: a macroscopic scale representing the global wind turbine system under simplified environmental loads and a local scale which models the response of the cables at the wires level.

From the global model, implemented in an industrial software, DeeplinesTM, tension and curvature distributions along the mooring lines are obtained.

The local model of the wire rope has been implemented in ABAQUS®v6.14. It models single wires with beam elements, in order to reduce the computational cost. Since a wire rope is made by a great number of wires (121 in our case), it seems not affordable to model all of them in a single analysis. Alternatively, we propose to decompose the local model into subparts, modeling just some wire layers at each time.

Contact modeling

Edge-to-edge, node-to-surface and surface-to-surface contact algorithms have been tested and the results have been compared with the analytical predictions proposed in [2] and [3]. In order to make use of the latter two, the idea has been to track the actual external surfaces of wires by linking shell elements to the beam nodes thanks to the use of Abaqus Multi-Point Constraints in order to follow the beam deformation. Moreover comparisons between small displacements and large sliding hypothesis have also been performed.

Local model results

The aim of the local model is to link the global quantities, namely tension and rope curvature, to local quantities that govern the fatigue damage at the wire level. In particular, we are interested in computing accurately the axial strain in the wires, the normal and tangential contact stresses and the relative movements among the wires. The performances of each local model is shown through parametric studies which enlighten the choice of the input parameters linked to contact modeling and mesh discretization which allows to obtain reliable results.

Since the problem is highly nonlinear due to the presence of friction and possibly large slidings between wires, loading/unloading behavior is studied.

The choice of the boundary conditions to prescribe on the local model is also carefully investigated in order to avoid any edge effect when coupling the two scale models.

The final objective of this work, once the fatigue law will be chosen, is to compute the cable fatigue damage for each environmental state. By considering the probability of occurrence of each of these states, the fatigue damage would then have to be estimated during the structural lifespan.

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