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Model reduction for non-linear structural problems with multiple contact interfaces: *application to the modeling of fowt mooring lines*

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The context of this work concerns the simulation of the loading on a part of a mooring line of a floating offshore wind turbine in order to accurately predict its fatigue life. Mooring lines are usually constituted by spiral strand wire ropes, which consist in a complex assembly of steel wires wrapped together in a twisted helical assembly of different wire layers around a single core wire. Due to their peculiar architecture, tension and bending loadings induce complex frictional phenomena between the wires that may induce fretting fatigue damage. A direct finite element analysis of the wire mechanics in order to predict fatigue life is computationally costly, since such kind of problem involves simulating the complex evolution of contact and friction conditions between the wires of the wire rope [1, 2]. In order to overcome these difficulties, we will focus on model reduction methods but also on domain decomposition methods in order to efficiently deal with the multiscale content of a non-linear problem with multiple contact interfaces.

The main challenges of the problem rely on the fact that the application of model reduction for structural problems involving a large number of frictional contact interactions is a challenging issue: in fact a reduced-order model may not efficiently capture and represent singular and propagating phenomena at the contact interfaces, such as long frictional cracks, macroslicing, sliding fronts and contact detachment between the wires.

In literature one can cite a posteriori approaches with reduced basis enrichment such as the non-negative matrix factorization method [3] or the cone-projected greedy algorithm [4]. A priori methods, which build the reduced basis on the fly throughout the computation, rely on the Proper Generalized Decomposition (PGD) [5] in the framework of the LATIN non-incremental nonlinear solver [6].

In this work, the proposed strategy aims at solving the frictional contact between the spiral strand wires in a robust and efficient way. It combines the following techniques : 1) Domain Decomposition Methods (DDM), in particular the mixed DDM based on the LATIN method [2]; 2) A priori model reduction based on the PGD. This approach will be investigated in order to reduce the computational cost of the analyses.

In this context, the first step is to investigate the potential reducibility of the addressed problem. An a posteriori SVD analysis has been performed on the solution of a tension and bending calculation on a metric cable section developed in [1, 2] subjected to small-amplitude oscillating loads around a pre-loaded state. A general good potential for reducibility for the different contact quantities (normal contact forces, frictional forces, inter-wire slip) is observed, due to the small variations in contact conditions induced by the particular loading. The outermost layers result to be the most critical especially for frictional forces, where bending effects are more pronounced and the contact conditions are more variable. Space modes depict a multi-scale behaviour with first global structural modes and subsequent localized modes around the sliding zones. This suggests that a multiscale computational strategy may be beneficial.

Thereafter academic examples which are representative of the physical problem at hand have been investigated with the proposed approach. A one-dimensional benchmark model of a wire of the wire rope, subjected to

traction and pressure and in contact with a frictional interface, has been analyzed to highlight how the introduction of domain decomposition, allowing for the separation of sticking and sliding zones, allows for more efficient creation of local reduced bases in order to be more accurate in areas where it is needed. The analysis also shows that domains with similar contact conditions present similar modes, which suggests the idea of sharing reduced bases in order to improve efficiency. The introduction of a proper coarse-scale problem for the DDM strategy allows to improve performances.

Finally, the LATIN-based multiscale mixed DDM with PGD [7, 8] is applied to two-dimensional benchmark contact problems, representative of a layer of wires of the wire. It is shown to what extent the DDM coarse-scale problem and the introduction of the PGD, which builds reduced basis per subdomain, can be efficient in the case of multiple contact interfaces.

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