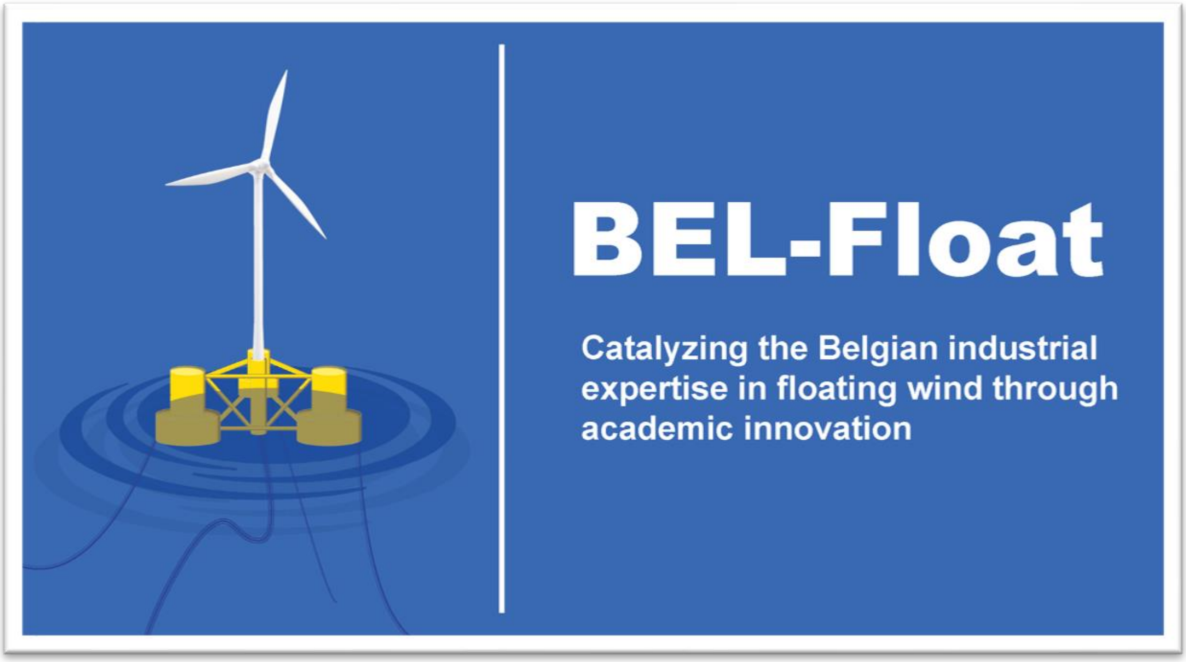

BEL-Float

Topic 6 – Dynamic power cables stress and integrity

Deliverable 1 – Multi-dimensional modelling strategy

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Contents

1. Chapter 1 – Introduction

1.1. Context within BEL-Float

This report presents a summary of the multi-dimensional modelling strategy developed within the scope of Topic 6 to integrate global and local analyses of the mechanical response of a dynamic power cable, implemented within the context of floating offshore wind turbines. The coupled global-local analysis aims to evaluate the overall deformation behavior of a dynamic power cable and calculate the internal stresses acting on individual cable components. This document constitutes the first deliverable (D1.1.6.1 - M15) for Topic 6 of the BEL-Float project.

1.2. Problem statement

The electricity generated by floating offshore wind turbines is transmitted through dynamic power cables to the shore. The dynamic power cables face challenging environmental and loading conditions due to the motions of the floating platform and the sea currents [1]. These harsh loading scenarios pose a risk of fatigue damage of the cables, potentially diminishing their operational lifespan. Therefore, the mechanical behavior of power cables must be carefully predicted to ensure a reliable design that can fulfill the economic and technical challenges that arise [2].

For this purpose, both global and local analyses of dynamic power cables are performed. In the global analysis, the overall mechanical behavior of the cable in response to the sea currents and floating platform motions is modelled. From the global deformation modes (bending, tension and torsion), section loads can be then extracted to drive the local analysis. In the local analysis, sub-models of the dynamic power cable are used to calculate the time series of stresses acting in individual components. These can subsequently be used to estimate the fatigue life of each cable component [2].

Figure1 illustrates the proposed multi-dimensional modelling strategy that integrates the global and local analyses. The global analysis will be conducted in collaboration with the University of Bergen, one of the two Norwegian academic partners in this project, during the secondment that the PhD researcher is projected to undertake in 2025. In contrast, the local analysis will be carried out at Ghent University. Section 2 provides a detailed explanation of the numerical modelling strategy.

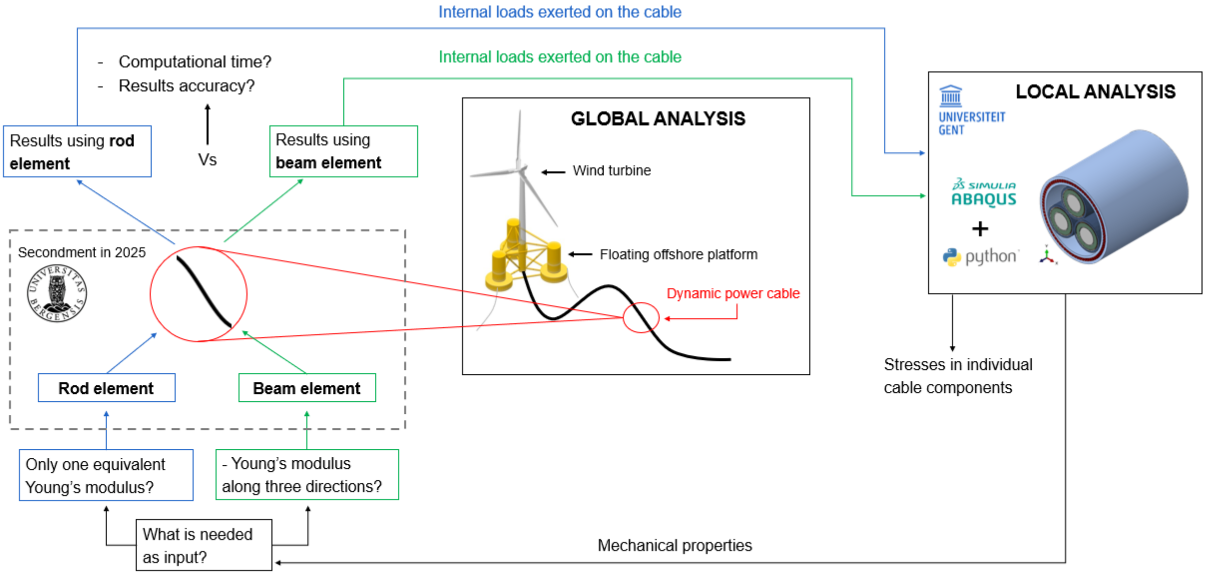

Figure 1: proposed multi-dimensional modelling strategy

2. Chapter 2 – Coupled global-local analysis

2.1. Global analysis

As explained in Section 1.2, the global analysis aims to assess the overall mechanical behavior of the dynamic power cable. The cable considered in this study is a three-core power cable, which can be modelled using either beam elements or nonlinear rod elements, the latter of which were developed by the academic partner, the University of Bergen. The primary distinction between these modelling approaches lies in the deformation modes they account for: rod elements capture only axial and bending deformations [3], whereas beam elements also include torsional effects.

Regarding the boundary conditions, and inspired by the work of Leroy et al. [2], one end of the dynamic power cable is connected to the floating platform, where it experiences motion induced by the wind and sea waves. The other end is assumed to be anchored at the seabed, representing a fixed point. Figure 2, adapted from the work of Leroy et al. [2], illustrates the configuration of the power cable for the global analysis, where the time series of the floating platform's displacements and rotations are applied at one cable end. These time series are derived from Topic 1 – operational and towing performance – of the BEL-Float project.

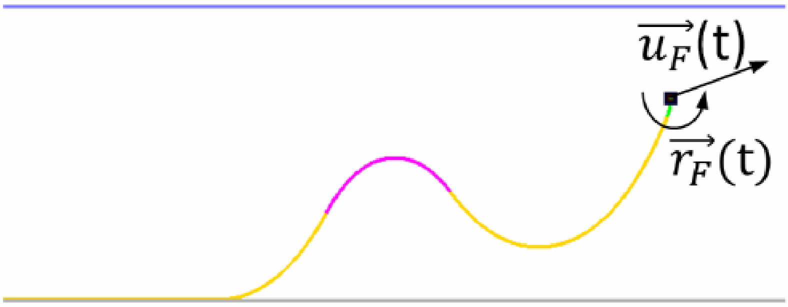

Figure 2: Power cable model for global analysis. Leroy et al. [2]

The internal loads acting on the cable are computed at the critical zones of interest, where the curvature variation is most significant. Consequently, the global analysis primarily focuses on the bending behavior of the dynamic power cable. These computed global loads serve as input for the local analysis. The following figure illustrates the proposed global analysis.

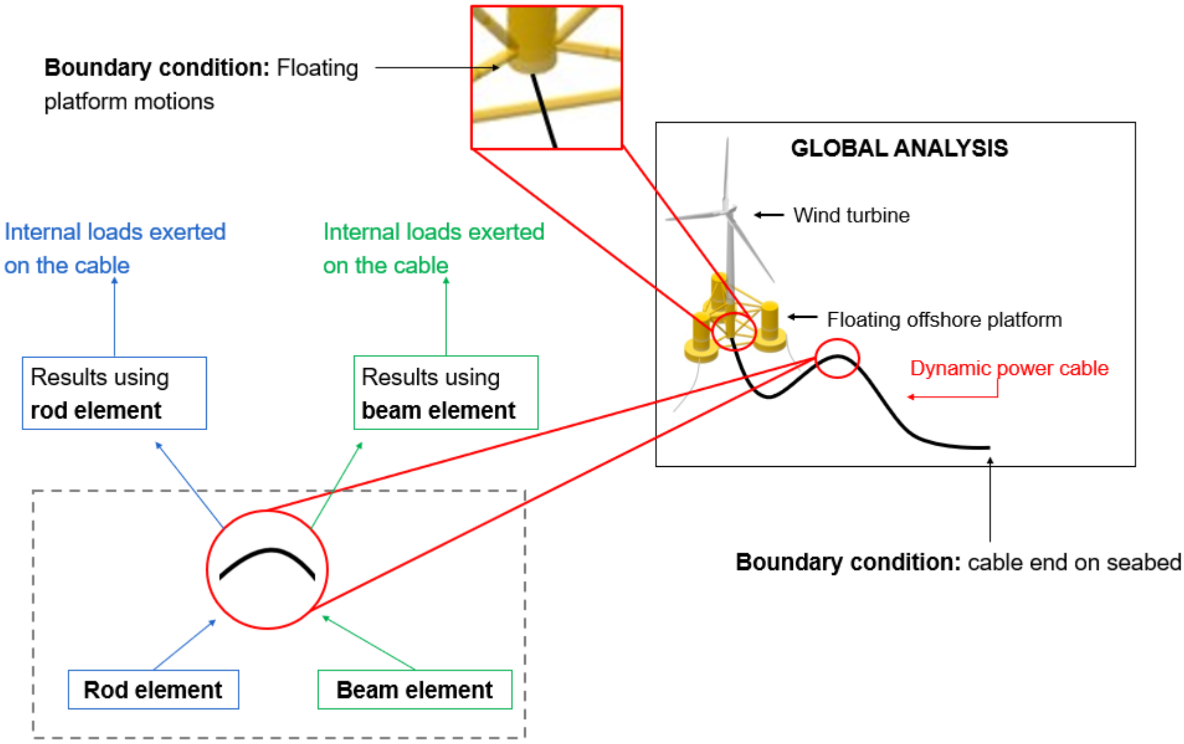

Figure 3: proposed global analysis of the dynamic power cable

2.2. Local analysis

The primary objective of the local analysis is to compute the fatigue-driving stresses in the dynamic power cable components. Following the global analysis, section loads derived from the global deformation modes (such as bending, tension, and torsion) are used to drive the local analysis.

The finite element (FE) solver Abaqus 2023 [4] is employed for the local analysis. A key consideration in the local analysis is a well-balanced trade-off between the level of modelling detail and computational cost. Critical parameters that must be accounted for include the helical shape of the components, inelastic material behavior, contact conditions, and large deformations.

2.2.1. Finite element (FE) model generation

The open-source programming language Python [5] is used to develop a script for generating the Abaqus input file required for the local analysis of the cable. This script offers significant flexibility, enabling the creation of Abaqus FE models with varying levels of modelling detail. For instance, the script can produce a simplified cable geometry in which all the components are assumed to be straight, neglecting any helical shape. Alternatively, the geometry can be refined to include the helical configuration of the armouring wires, or a more detailed representation can be generated, incorporating the helical geometry of multiple cable components. This adaptability ensures that the level of modelling complexity can be tailored to the specific requirements of the local analysis. Figure 4 illustrates two such model variations.

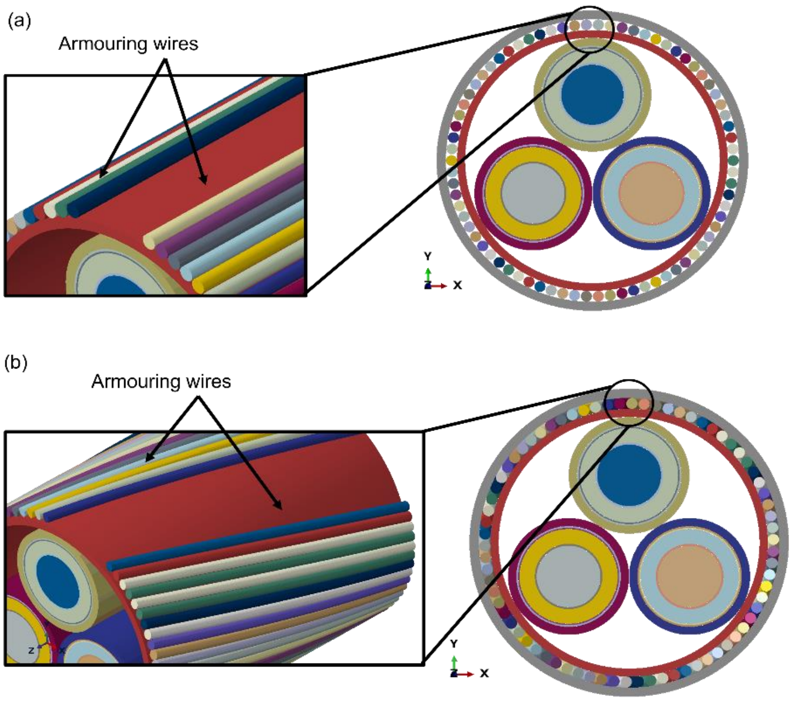

Figure 4: (a) straight armouring wires; (b) armouring wires with helical shape

On the other hand, the armouring wires, which provide the cable with bending flexibility and resistance to axial and torsional loads, can be modelled using two types of elements available in Abaqus: solid 3D continuum elements (e.g. C3D8R) or beam elements (e.g. B31). The modelling strategy that implements beam elements provides an effective balance between accuracy and numerical efficiency, and it results in lower computational time compared to 3D solid elements [6]. This strategy is inspired by the works of Fabien Ménard and Patrice Cartraud [6] and [7]. As illustrated in Figure 5, the algorithm developed in Python enables the armouring wires to be modelled using either continuum or beam elements in Abaqus.

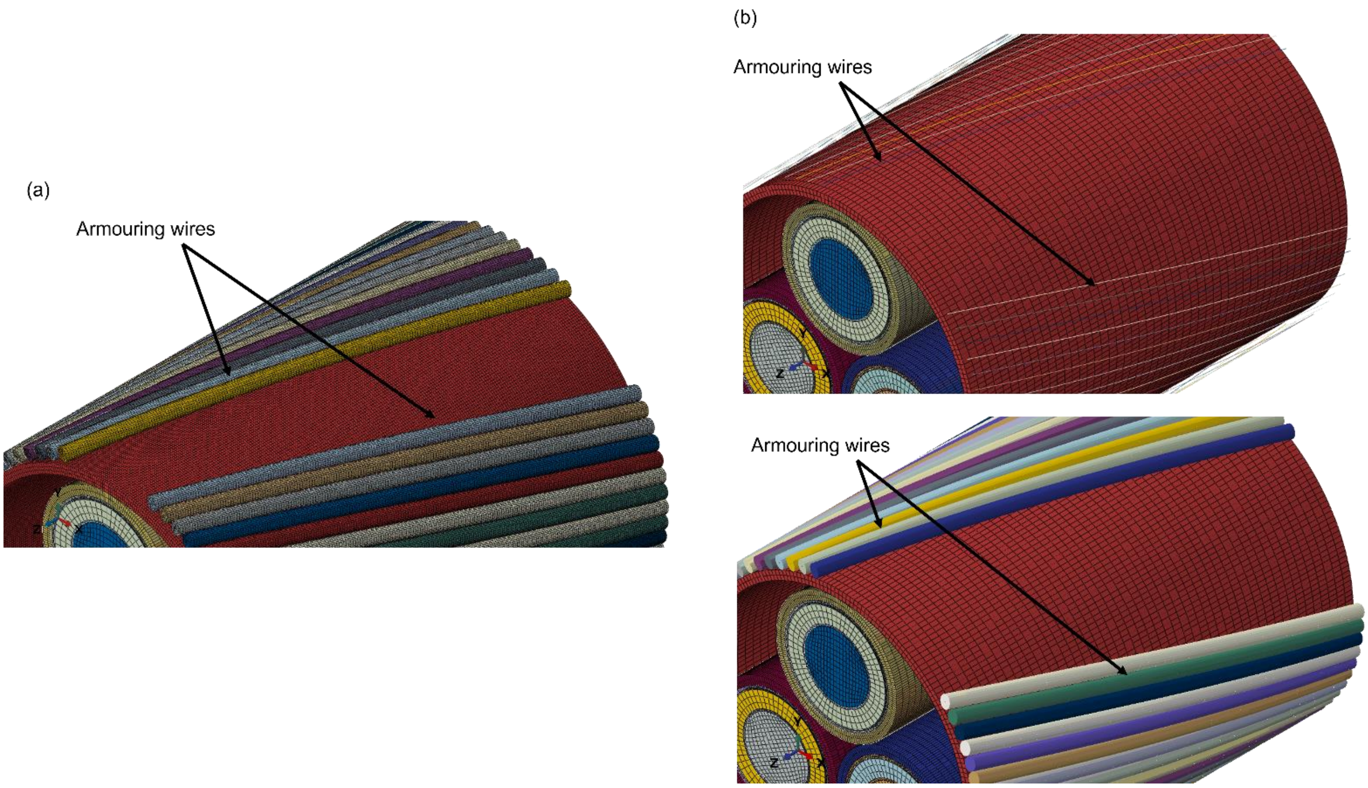

Figure 5: Armouring wires with helical shape: (a) modelled using solid elements; (b) modelled using beam elements

Finally, the aforementioned script automatically defines the contact conditions, such as friction and normal separation, between the power cable components. It also applies the boundary conditions, including the deformation modes exerted on the cable and computed during the global analysis. This method significantly reduces the time required to generate the finite element (FE) model in Abaqus for the local analysis compared to manually defining these conditions and modelling the cable components using the Abaqus software.

2.2.2. Stresses in individual cable components

The time-dependent stresses in the cable components are determined using the finite element (FE) model developed for the local analysis in Abaqus. These stress time series are then used to compute the fatigue life of each cable component. Due to local model non-linearities introduced by interactions between the cable components, such as friction, the rainflow counting method can be applied to perform an accurate fatigue analysis [2].

The following figure illustrates the proposed local analysis.

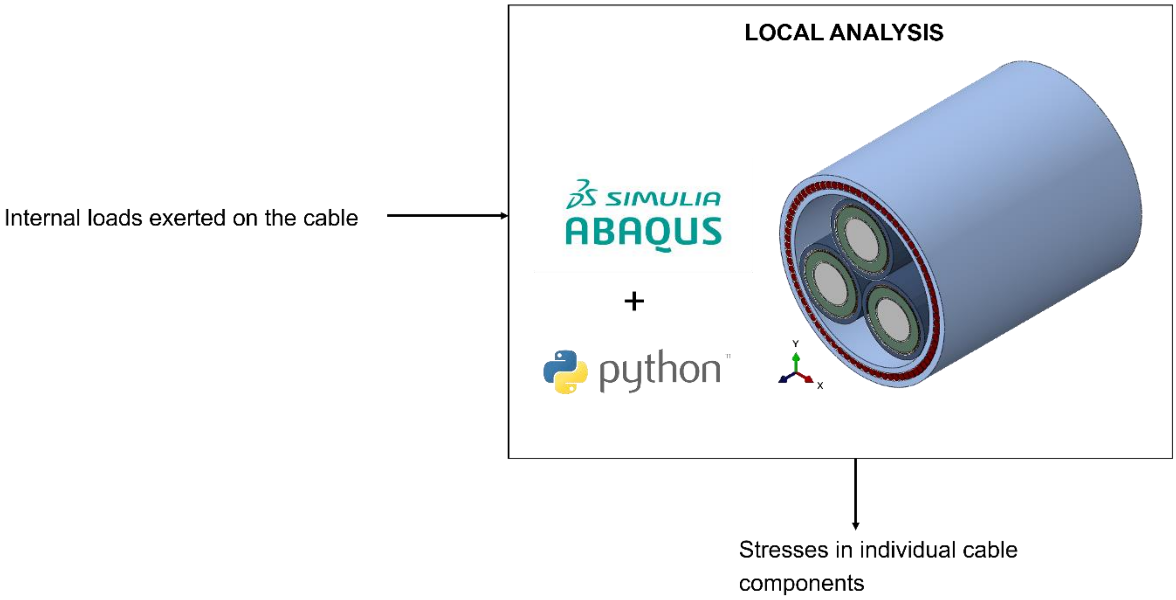

Figure 6: proposed local analysis of the dynamic power cable

2.2.3. Coupling global and local analyses

As previously explained, the deformation modes from the global analysis — such as bending, torsion, and tension — serve as input for the local analysis. For the global analysis, however, equivalent mechanical properties of the power cable are required to model the beam or rod elements used in the simulation.

The power cable exhibits a high level of complexity due to the varying mechanical properties of its constitutive components. When subjected to the aforementioned deformation modes, the cable's cross-section does not remain planar. Consequently, based on the resulting deformation from the local analysis, an equivalent average plane must be derived. This average plane represents the cross-section that most closely approximates its actual deformed configuration. Once determined, the normal direction of this plane can be established, allowing for the derivation of geometric properties such as bending curvature.

Additionally, other quantities such as bending moment, shear load, shear strain, normal load, and normal strain can be computed. To ensure accuracy, these quantities and the equivalent plane must be evaluated sufficiently far from the cable ends to avoid boundary effects that could compromise the results.

Finally, using the stress and strain distribution obtained in the local analysis, it is possible to derive the equivalent mechanical properties required for the beam or rod elements employed in the global analysis.

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