Numerical Analysis of Carbon Fiber Cables for Mooring Lines
Under Tensile and Bending Loading

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Carbon fiber reinforced polymer (CFRP) cables present outstanding performance in terms of specific stiffness and strength, but their behavior is not yet fully understood, especially regarding the influence of the cable’s construction on its properties. In this study, the mechanical performances of a standard \( (6 + 1) \times 7 \) stranded CFRP cable composed of 49 rods (wires) and a \( 1 \times 61 \) spiral CFRP cable (61 rods) under tensile and bending loading were analyzed using a numerical model. The spiral cable showed higher load at break (980 kN) compared to the stranded cable (878 kN) and higher minimum bending radius.

INTRODUCTION

Carbon fiber reinforced polymer (CFRP) cables perform better in terms of specific stiffness and strength, along with fatigue and corrosion resistance, compared to traditional steel cables (Fabbrocino et al., 2016; Dhand et al., 2015; Meier, 2012). They are natural candidates for harsh environments such as offshore applications. While the cost of composite materials is generally greater than that of traditional structural materials, the extended life of a composite structure results in reduced long-term structural costs (Fabbrocino et al., 2016). Other benefits of CFRP cables include low energy consumption during the manufacturing, construction, and execution processes (Dhand et al., 2015; Son et al., 2013; Wang and Wang, 2015).

There are very limited experimental data available in the literature for these novel cables, and theoretical solutions still need to be further developed. According to Meier (2012), composite cables are much more recent for industrial applications, and in order to encourage their use it is necessary to fully study and understand their behavior through analytical solutions, numerical models, and experimental tests.

On the other hand, several theoretical approaches have been developed for isotropic cables (metallic wire ropes), some of them with many simplifications, nonetheless still showing good agreement between predictions and experimental data. Costello (1997) extensively investigated isotropic cables, developing analytical models based on beam theory, and he treated the wires as rods, allowing bending and torsion due to tensile stiffness analysis, unlike most of the previous analytical solutions.

Cables can be manufactured with two main constructions: (A) where the direction of the lay of the wires in the outer layer or strand is in the opposite direction to the lay of the inner layer or strand or (B) where the direction of the lay of the wires in the outer layer or strand is in the same direction to the lay of the inner layer or strand. Usabiaga and Pagaldy (2008), also using beam theory, developed an analytical solution for stranded cables for both construction types A and B submitted to tensile stress allowing for rod rotation but neglecting the Poisson effect. They compared their model with the analytical solution of Costello (1997) for Poisson ratios of 0.0 and 0.3 and verified a small difference. The resulting torque at the cable ends was higher in the type B construction.

In the numerical area, Erdonmez and Imrak (2011) analyzed a \((6 + 1) \times 7\) stranded cable using the finite element method (FEM). They investigate the minimum length to be modeled and still give reliable results. They executed both frictionless elastic (multilayered) and frictional elastic-plastic (single-layered) analyses and found good agreement with the analytical solution of Costello (1997). They concluded that wire contraction played a small role in mechanical behavior. Jiang (2012) analyzed isotropic single-layered stranded cables in bending, considering plastic strain and friction, and also reported good agreement with the analytical solution of Costello (1997). The effect of the friction coefficient was also studied by Raoof and Knaircanic (1998), who suggested that, with sufficient friction, a broken wire will be capable of supporting its total share of the load in a relatively short length because of the presence of additional compressive forces exerted by the neighboring spiral strands in a wire rope. Ghoreish et al. (2007) compared their FEM model results with experimental data for a \( 1 \times 7 \) single-layered cable under axial loading, varying the helix angle, and observed a small effect. They also analyzed that cable through nine different analytical models, including that of Costello (1997) for variable helix angle (\(60^\circ–90^\circ\)). All models provided good torsional stiffness results agreement for helix