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Analytical modeling of synthetic fiber ropes subjected to axial loads. Part I: A new continuum model for multilayered fibrous structures

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Abstract

Synthetic fiber ropes are characterized by a very complex architecture and a hierarchical structure. Considering the fiber rope architecture, to pass from fiber to rope structure behavior, two scale transition models are necessary, used in sequence: one is devoted to an assembly of a large number of twisted components (multilayered), whereas the second is suitable for a structure with a central straight core and six helical wires (1 + 6). The part I of this paper first describes the development of a model for the static behavior of a fibrous structure with a large number of twisted components. Tests were then performed on two different structures subjected to axial loads. Using the model presented here the axial stiffness of the structures has been predicted and good agreement with measured values is obtained. A companion paper (Ghoreishi, S.R. et al., in press. Analytical modeling of synthetic fiber ropes, part II: A linear elastic model for 1 + 6 fibrous structures, International Journal of Solids and Structures, doi:10.1016/j.ijsolstr.2006.08.032) presents the second model to predict the mechanical behavior of a 1 + 6 fibrous structure.

Keywords: Fiber rope; Yarn; Aramid; Multilayered structures; Analytical model; Testing

1. Introduction

Synthetic fiber rope mooring systems, which are often composed of steel chain at the ends and a central synthetic fiber rope, are increasingly finding applications as offshore oil exploration goes to deeper sites. Previous researchers have shown that such mooring lines provide numerous advantages over steel mooring lines

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(steel wire ropes and chains), particularly in deep water applications for which the large self-weight of steel lines is prohibitive (Beltran and Williamson, 2004; Foster, 2002). It is therefore essential to be able to model the mechanical behavior of very long synthetic mooring lines in order to reduce the need for expensive tests under varying parameters and operating conditions.

Large synthetic fiber ropes are assemblies of millions of fibers and characterized by a very complex architecture and a hierarchical structure in which the base components (fiber or yarn) are modified by twisting operations. This structure is then a base component for the next higher structure. Its hierarchical structure leads to the hierarchical approach where the top is the fiber rope and the bottom is the base components, with several different types of elements between the base component and the fiber rope, i.e. yarn, assembled yarn and strand. Fig. 1 illustrates this hierarchical structure.

Considering the fiber rope architecture, it consists of two different types of structure: one is a structure with a central straight core and six helical components (1 + 6), whereas the second is an assembly of a large number of twisted components (multilayered), see Fig. 2. So to pass from fiber to rope structure, two scale transition models are necessary, used in sequence. The results of the model at each level can be used as input data for the model at the next higher level. Use of this approach from the lowest level, at which mechanical properties are given as input, to the highest level of the rope determines the rope properties. Based on this strategy, the transition models can be used to analyze synthetic fiber ropes of complex cross-section. Fig. 3 shows the typical hierarchy ranking from the smallest level to the highest level for a 205 ton break load fiber rope.

The focus of this paper is the modeling of the static behavior of a fibrous structure with a large number of twisted components subjected to axial loads, starting from the mechanical behavior of the base component, and the geometric description of the rope structure.

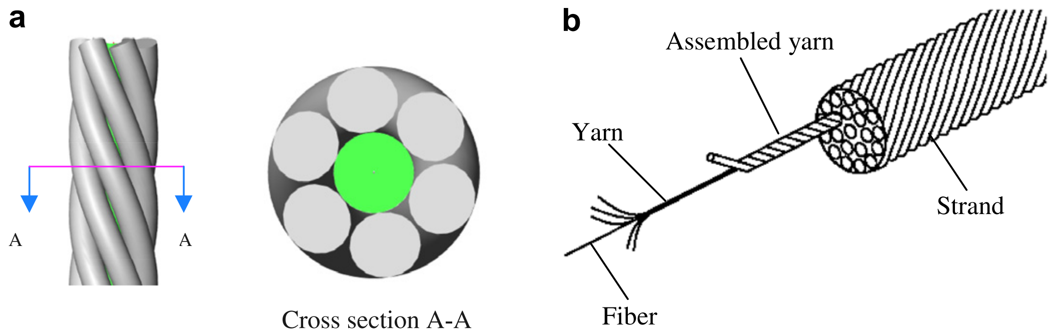

Fig. 1. Synthetic fiber rope structure. (a) Fiber robe with 1 + 6 strands and (b) construction of a strand.

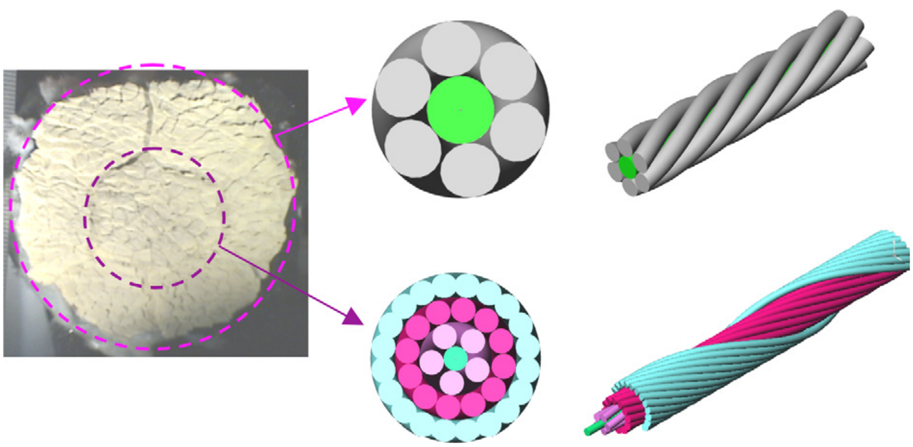

Fig. 2. Cross-section of a synthetic fiber rope (205 ton break load); the rope represents a 1 + 6 structure, core and strands are assemblies of a large number of twisted components.