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On finite element analysis of sling wire rope subjected to axial loading

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ABSTRACT

This paper explores some aspects of finite element modeling of 7 × 19 IWS (wire rope with Independent wire strand core), as mostly used sling wire rope. First, the 1 × 19 stainless steel wire strand core was investigated. The numerical analysis was carried out by the finite element method. In this analysis two different types of contacts were investigated: bonded and frictional contact. The strand core was subjected to two different types of axial loading. The obtained results were compared with the solutions calculated from the available literature. Finally, using the advanced modeling techniques, the parametric 3D model of 7 × 19 IWS was also analyzed by using the finite element method, in order to provide a better understanding and, hence, prediction, of the mechanical behavior of the sling wire ropes.

1. Introduction

High strength wire ropes are very important structural members which are used for transmitting tensile forces. Because of their flexibility and high strength, wire ropes are in widespread use throughout the mechanical, electrical, mining and naval engineer industries. Applications include lifts, suspension bridges, electrical power transmission, aircraft arresting cables, mining equipment, safety and anchoring cables for meteo guyed musts, or mooring for a floating platforms. They are also a necessary part of various equipment that has been designed specifically to aid in the movement of materials, machinery, etc. They include: tower and harbor cranes, derricks, hoists, powered industrial trucks, conveyors. All these transport devices rely upon wire ropes, to be more specific, wire rope slings, to hold their suspended loads.

Slings are the most commonly used piece of materials-handling and lifting apparatus. They offer a strong, dependable, durable and economical option for most lifting applications. Their popularity is enhanced by the numerous sling configurations (Fig. 1) available to support a broad range of applications.

In order to predict the wire rope behavior, hence sling wire rope behavior, several theoretical models and analytical studies have been presented in the literature, (Love, 1944, Costello, 1990). Most of them neglect frictional and contact effects, but there are some, that takes those effects into consideration.

As technology and computer sciences were developing and became more available, numerical analyses started to be frequently used in predicting the wire rope behavior. The use of these analyses came as a need, because it was often required to conduct various tests during exploitation to evaluate wire rope structural condition and bearing capacity and to detect damage resulting from the repeated working load. Knowing that experimental work on wire rope requires specific, large and expensive testing devices, numerical analysis such as finite element analysis, as non-destructive method, was the logical next step in the wire rope behavior studies.

One of the first finite element analyses of simple straight strand has been presented by Jiang et al. (2000). Elata et al. (2004) developed a new model for simulating the mechanical response of an independent wire rope core (IWRC). Elastic–plastic contact problem of laying wire rope using finite element analysis has been presented in Sun et al. (2005).

A realistic 3D structural model and finite element analysis of a simple wire strand has been briefly explained by Erdonmez and Imrak (2009). The same authors presented the 3D solid model and numerical analysis of IWRC in Erdonmez and Imrak (2010).

Some of the mentioned analyses ignored frictional effects, but there were some (Jiang et al. (2000), Elata et al. (2004); Sun et al., 2005, Imrak and Erdonmez 2009, 2010; Kastratović and Vidanović, 2010), that took those effects into consideration. However, analysis of other contact effects in three layered ropes was neglected in available literature. Also, all of them introduced axial loading as applied axial strain, except in Kastratović and Vidanović (2011) were authors used axial force which was evenly distributed between wires.

The mathematical geometric models in CATIA V5 software of the single-lay wire strands and double-lay wire ropes with defined

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Fig. 1. Sling wire rope application in lifting and transport processes.

initial parameters are presented by Stanova et al. (2011a). The same authors were focused on a multi-layered strand with a construction of the 1+6+12+18 wires (four-layered strand, with 6 wires in second, 12 wires in third and 18 wires in fourth layer), which was analyzed in a finite element program (ABAQUS/Explicit software) (Stanova et al., 2011b).

Páczelt and Beleznai (2011); Beleznai and Páczelt (2012) also have published papers, where the friction and contact are considered in case of one- and two-layered wire rope strands. In these papers the p- version beam finite elements were used with special contact elements applying the Hertz theory and Coulomb dry friction law. They considered relative displacement, wear and Poisson-effect, contact and friction between the wires in the case of the small elastic deformation theory.

However, it is still very difficult to model and analyze wire ropes, using numerical methods, such as finite element method. Also, this kind of analysis requires substantial computer resources. Nevertheless, numerical analysis must be employed to provide a better understanding, and hence prediction, of the mechanical behavior of the wire rope strands, thus reducing the need for expensive tests (because of which the experimental results reported in the literature are very limited). In order to accomplish all of that, the aim of this paper was to explore some aspects of 3D modeling of a sling wire rope using the finite element method based computer program with special emphasis on different types of contacts and different types of axial loading.

2. Finite element model and analysis

Model of the wire rope considered here is shown in Figs. 2 and 3. As it can be seen, first the 1 × 19 wire rope was investigated. It is a stainless steel core of a 7 × 19 wire rope with independent wire strand core, or shorter 7 × 19 IWS. The 7 × 19 IWS is extremely flexible in use because of its strength and high corrosion resistant qualities. It is used in general engineering applications, especially stainless steel wire rope slings (Safety sling online catalogue, 2011).

The 3D finite element model of the 1 × 19 wire rope was created (Fig. 4 and 5). First, the 3D parametric geometrical model was created and then imported into the finite element based computer program. This program allowed specification of material properties, generation of finite element mesh, application of loads, and contact definition as well as solving and obtaining necessary output data.

Finite element used for meshing all analyzed models was a brick solid element that is used in 3D modeling of solid structures, as default element. The same kind of element was usedin [7]. It is a higher order 3D 20-nodes solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities.

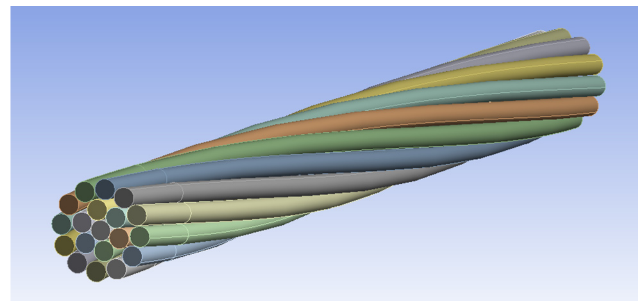

Fig. 2. 1 × 19 stainless steel core.

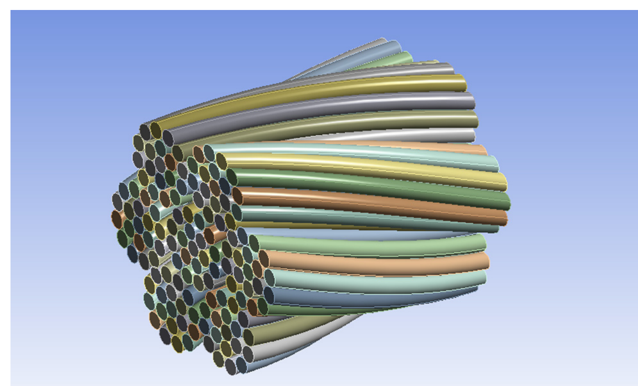

Fig. 3. 7 × 19 stainless steel wire rope.

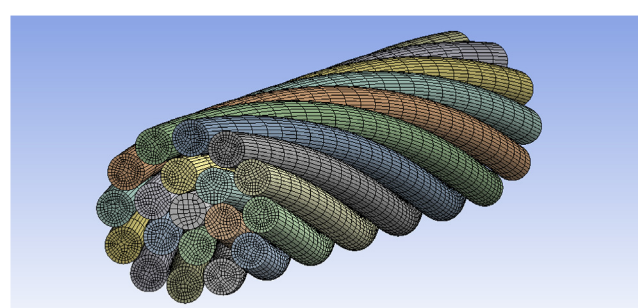

Fig. 4. 3D finite element model of the 1 × 19 wire rope core.

It also has mixed formulation capability for simulating deformations of nearly incompressible elasto-plastic materials, and fully incompressible hyperelastic materials. This type of element is well suited to modeling irregular meshes (such as those produced by various CAD/CAM systems), which was the case here.

Another important issue for this particular problem represents the contacts between wires and friction. Regardless of friction, contacts between wires exist and must be taken into consideration. They determine how the wires can move relative to one